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The Jurassic and Lower Cretaceous of Wadi Hajar, southern Yemen

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SYNOPSIS. Jurassic and Lower Cretaceous rocks in Wadi Hajar are about 600 m thick, and consist of the Kohlan (oldest), Shuqra, Madbi, Naifa (Billum and Kilya Members), Hajar (Arus and Mintaq Members) and Qishn Formations, of which the Hajar Formation and its two members and the two members of the Naifa Formation are newly proposed here. The arenaceous Kohlan Formation overlies the Precambrian and contains no fossils in Wadi Hajar, but is dated elsewhere as Lower and Middle Jurassic. The calcareous Shuqra Formation is Callovian in age and contains many brachiopods, bivalves and gastropods. The argillaceous Madbi Formation also contains many brachiopods and molluscs, and a few ammonites that date it as Oxfordian. The Naifa Formation, Billum Member is calcareous with occasional Upper Oxfordian to Upper Kimmeridgian ammonites; the Kilya Member is more marly and contains many Beckeri Zone (Upper Kimmeridgian) and Hybonotum Zone (Lower Tithonian) ammonites. After a disconformity representing the remainder of the Lower Tithonian, the Hajar Formation, Arus Member is calcareous and marly, with gypsum veining and microbialite boulders in the lower part, and contains many Upper Tithonian ammonites. The Mintaq Member is highly calcareous, and contains many top Tithonian to mid-Berriasian ammonites. After another disconformity missing out the Valanginian and Lower Hauterivian, the Qishn Formation consists of sandy limestones, from which an Upper Hauterivian ammonite was obtained, followed by the *Orbitolina* Limestone of Upper Barremian to Aptian age.

INTRODUCTION

From its mouth on the Gulf of Aden, 430 km ENE of Aden and 80 km SW of Mukalla, Wadi Hajar extends inland for approximately 120 km north-westwards (Fig. 1). In Jurassic times the area now occupied by the south-eastern part of Wadi Hajar was part of a relatively slowly subsiding shelf sea, compared to the more rapidly sinking Hajar Basin to the north-west and the Balhaf Basin to the south-west. In this area Jurassic and Lower Cretaceous rocks lie directly on basement metamorphic and igneous rocks of Precambrian age, and they are overlain by younger Cretaceous and Tertiary rocks. Because of its large areas of good outcrop and relative ease of access, Wadi Hajar has been the scene of much exploratory collecting in recent years by those seeking standard successions through the Jurassic and suites of macro- and microfossils, for use in age determinations of borehole successions in basinal areas that lack outcrops of Jurassic rocks. In May 1991 two specimens of an undescribed Berriasian species of *Spiticeras* from the Mintaq Salt Dome in the upper part of Wadi Hajar were submitted to one of us (MKH) for determination. It was immediately clear that these represented an ammonite fauna and an age that had not been described before from Yemen. We were able to visit Wadi Hajar in November 1991, when we obtained more than 100 specimens from this new and splendid Berriasian ammonite fauna at Mintaq. We also collected about 30 ammonites from a difficult-to-interpret section in eastern Jebel Billum, of Upper Tithonian age, and several Upper Oxfordian ammonites from a nearby locality just above the base of the Naifa Formation. The latter ammonites were from one of two faunas that had been sampled by previous investigators, and after determination by Drs L.F. Spath and W.J. Arkell, ought to have resulted in an Upper Oxfordian to Kimmeridgian age being given to the Naifa Formation. We located and redetermined these previous collections, and we were then sent for determination some beautifully preserved examples of the basal Tithonian ammonite *Katroliceras*, as well as some top Kimmeridgian ammonites. These led us to believe that there was a great deal more variety in the Wadi Hajar Kimmeridgian and Tithonian ammonites than had been described before, and that although the Mintaq Salt Dome and Jebel Billum/Naifa Cliff/Wadi Kilya rocks were of very similar appearance, they contained entirely different ammonite faunas of very different dates, ie. Berriasian, and Upper Oxfordian to basal Tithonian respectively.

A new tentative correlation was drawn up of these Upper Jurassic rocks from Mintaq to Wadi Arus, Jebel Billum, Naifa Cliff and Wadi Kilya, that fitted in with the collections that were then available to us. With this as a working hypothesis, we made another visit to Wadi Hajar in January 1994. This yielded splendid collections of ammonites from both existing and entirely new localities and ages, and showed that the working correlation was largely correct, requiring modification only in detail. With the 580 ammonites collected on this second visit, we now had over 800 ammonites from the Jurassic and Lower Cretaceous of Wadi Hajar, all from known levels, and representing 14 biostratigraphical horizons from the middle of the Callovian to the middle of the Berriasian, the majority being from the top zone of the Tethyan Kimmeridgian to the Berriasian. Fossils of many other groups were also collected, foremost amongst them being Callovian and Oxfordian brachiopods that are abundant in the Shuqra and Madbi Formations. Numerous bivalves and a few echinoids were obtained from the same two formations, but in the Naifa and Hajar Formations faunas other than ammonites are much rarer or absent.

The purpose of this paper is to describe the Jurassic and Lower Cretaceous of Wadi Hajar between the south-easternmost locality at Al Ma'abir and the Mintaq Salt Dome, 65 km to the north-west (Fig. 1). As such it takes in the river section at Naifa Cliff and the nearby section in Wadi Kilya, both at Al Ma'abir, which together make up the type section of the Naifa Formation; the various sections in the outcrop along the southern side of Jebel Billum, where all the Jurassic formations are developed; the splendid exposures in the cliffs on both east and west sides of Wadi Arus and the road gorge climbing out of that wadi to the south-east, where there are exposures from the top of the Billum Member upwards, including the type sections of the Hajar Formation; and the exposures of the Mintaq Member in the Mintaq Salt Dome, where the beds have been

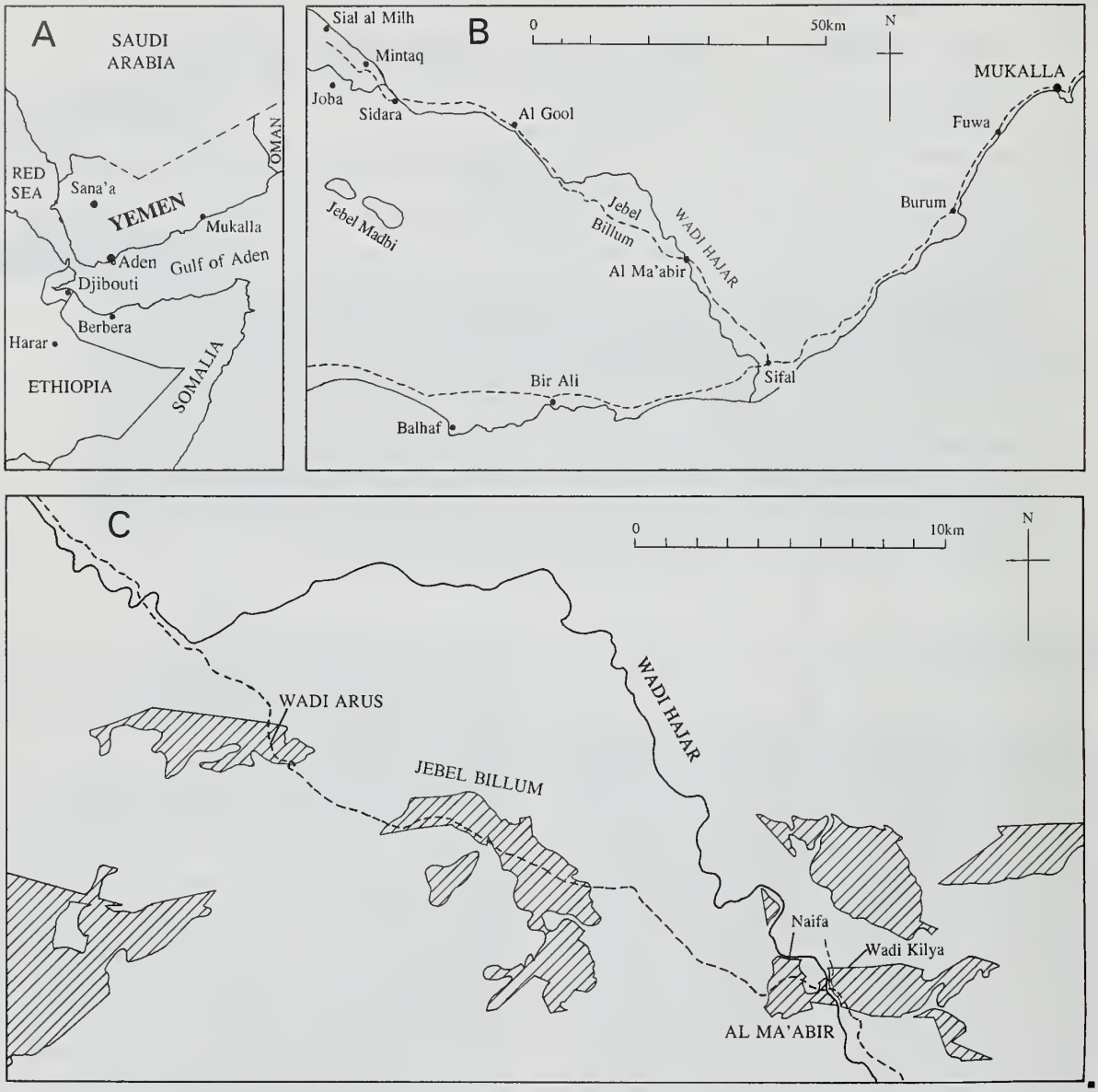


Fig. 1 A, location map of the southern part of the Arabian peninsula and north-east Africa. B, Wadi Hajar west of Mukalla extends from its mouth near Sifal to beyond the three salt domes of Mintaq, Joba and Sial al Milh, 90 km to the north-west. C, geological map of the lower part of Wadi Hajar from Al Ma'abir to Jebel Billum and Wadi Arus, showing the outcrop of Jurassic and basal Cretaceous rocks (hatched). The dashed lines on Figs 1B and 1C are roads.

pushed largely vertical by the rising core of the salt dome. The present paper, which deals with the lithostratigraphy and biostratigraphy, will be followed by papers describing the ammonites, brachiopods, echinoids and some of the bivalves.

PREVIOUS INVESTIGATIONS

Little, 1925

O.H. Little and H.M. Heald travelled up Wadi Hajar in February and March 1920 at the instigation of the Sultan of Shehr and Mukalla, mainly to investigate mineral deposits and agricultural methods. Accompanied by a retinue of 80–90 people, including 25 soldiers of the Sultan's private army for protection, they experienced great difficulty in passing through the formidable river gorge between Naifa and the mouth of Wadi Arus, at a time before the unmetalled road was constructed around the southern side of Jebel Billum. They penetrated Wadi Hajar as far as Jawl Bâhâwa (= Jol Ba Hawa; also the present Al Gool), but political and tribal reasons prevented them from going farther up the wadi to El Sidâra and thence to Mintaq. Nevertheless, Little made geological observations on the Jurassic outcrops at Naifa Cliff, Wadi Arus and near Hisn Bâqirdân (= Husn Ba Qirwan). The results were given in his paper (Little, 1925: 109–114). Three fragments of ammonites and three belemnites obtained from Naifa Cliff, and five bivalves and six brachiopods from Husn Ba Qirwan, were figured in the same paper by Stefanini (1925: 144–

208). Little (1925: pls 24, 26) drew vertical sections of the outcrop of the Naifa Formation in Naifa Cliff and in the east cliff in Wadi Arus, and suggested that oil shales of similar appearance in both sections were outcrops of the same bed. He was basically correct in making this correlation, though it is not now possible to interpret his more general section (Little, 1925: pl. 25) of the succession on the west side of Wadi Arus.

Beydoun, 1964

The exposures in Wadi Hajar formed a major part of Beydoun's (1964) description of the Jurassic over a much wider area in the south-eastern half of Yemen. This was based on field work by Z.R. Beydoun and E.K. Elliott in 1954–58, and resulted in the geological maps accompanying the published report (Beydoun, 1964: maps 1, 2) and the much more detailed unpublished reports held by British Petroleum Plc. Beydoun used four formation names for the Jurassic in Wadi Hajar – Kohlan Formation (oldest), Shuqra Formation, Madbi Formation, Naifa Formation (youngest) – though there are some difficulties in their interpetation because the type sections of the four formations are in widely separated parts of Yemen. Nevertheless, it is quite clear to which rocks Beydoun applied the formation names in Wadi Hajar, and our own work would not have been possible without the basic work done by Beydoun (1964: 30–46), in which he gave detailed lithological descriptions and long lists of fossils.

Lexique Stratigraphique International (Beydoun & Greenwood, 1968)

Formal definitions of the Kohlan, Shuqra, Madbi and Naifa Formations were given in the volume of the *Lexicon* that covered the southern Yemen area, from which it is clear that only the Naifa Formation has its type area in Wadi Hajar, though the type area of the Madbi Formation on nearby Jebel Madbi is only 20 km south-west of Wadi Hajar. On the other hand, the type area of the Shuqra Formation is at Shuqra, 80 km north-east of Aden, and 300 km south-west of Wadi Hajar, while the Kohlan Formation ought to have its type section in the Kohlan area north-west of Sana'a, though Beydoun (1968: 64) described his 'reference' section from its development at Al Ma'abir in Wadi Hajar.

Later mapping of the Wadi Hajar area

After the political changes in 1968–71, integrated geological mapping and exploration of southern Yemen was done in cooperation with geologists from three eastern European countries. The easternmost area extending as far as Mukalla was the province of geologists of the then German Democratic Republic, and this included maps for the area that contains Wadi Hajar. Maps were published in Aden by the Ministry of Energy and Minerals, Department of Geology and Mineral Exploration, of the then People's Democratic Republic of Yemen, on a scale of 1:100,000. The three sheets that have been used by us are D-39-49 (Jawl Ba Hawa), D-39-61/73 (Bir Ali/Balhaf) and D-39-62 (Mayfa Hajr), which we were able to consult through the kindness of BP Exploration. These maps have been of much value in locating the positions and extent of the sections we studied. They were prepared after some reconnaisance on the ground, followed by tracing geological boundaries and inserting detail from aerial photographs. The lithostratigraphical nomenclature used is largely that due to Beydoun, and some of the outcrops have to be interpreted with care, bearing in mind the errors and difficulties in his interpretation that are described below. One of these is the Madbi Formation on the Bir Ali/Balhaf map (D-39-61/73), from Jebel Madbi eastwards to the large area of outcrop around Jebel Timurah, which also includes the whole of the Naifa Formation as defined at its type locality at Naifa Cliff on the Mayfa Hajr map (D-39-62), where it is correctly mapped as Naifa Formation.

CORRELATION AND LITHOSTRATIGRAPHICAL NOMENCLATURE

On our first visit in November 1991, it became apparent that there was a significant unconformity within the 'Naifa Formation' in its outcrop at the eastern end of Jebel Billum. From beds above the unconformity some good Upper Tithonian ammonites were obtained, including some crushed top Tithonian berriasellids only 5 m below the base of the Qishn Formation (Upper Hauterivian-Barremian), which are much younger than the Upper Oxfordian to Upper Kimmeridgian ammonites that had been found lower in the Naifa Formation by Beydoun and other early collectors. The splendid new Berriasian ammonite fauna collected from the 'Naifa Formation' at Mintaq on the same visit was younger still.

Work in 1994 on all the sections (Al Ma'abir/Naifa Cliff/Wadi Kilya, Jebel Billum, Wadi Arus, Mintaq) led us to the conclusion that there are two different limestone formations in Wadi Hajar, separated by a series of marls, limestones and concretions, in the middle of which is a major unconformity or disconformity, where the whole of the Lower Tithonian is missing except for part of its basal zone (Fig. 2). Beydoun had correlated these two limestones, believing them to be separate outcrops of the same Naifa Formation, the consequences of which have had such a profound effect on all later work on the lithostratigraphy and biostratigraphy of the Jurassic in Yemen, that it is important to understand the origin of these errors.

The Naifa Formation is named from the development of limestones and marls at the type locality in Naifa Cliff, which is a river cliff about 2 km upstream from the road/river crossing at Al Ma'abir in Wadi Hajar. The top of the section at Naifa Cliff is overlain by recent river deposits, but at a nearby exposure in Wadi Kilya the Naifa Formation extends slightly higher into the base of the Lower Tithonian before being overlain by the Qishn Formation of Upper Hauterivian to Barremian age. Beydoun collected large perisphinctid ammonites from a horizon high in the Naifa Cliff section, which were determined by Dr W.J. Arkell as of Lower Kimmeridgian age. It is important to realise that Arkell was using 'Lower Kimmeridgian' in the north-western European sense, where it is equivalent to the whole of the Tethyan Kimmeridgian; this relationship is still valid today (ie. the Tethyan Kimmeridgian, divided into Lower Kimmeridgian and Upper Kimmeridgian, is equivalent to the Lower Kimmeridgian only of Britain), but this was not entirely clear in the mid-1950s when Arkell made these determinations, and the different north-western European and Tethyan divisions of the Kimmeridgian were not used consistently by Arkell (1956) in his *Jurassic Geology of the World*. Beydoun also collected some crushed ammonites from an horizon that is now known to be low in the sequence near Naifa Cliff, which were determined by Dr L.F. Spath as perisphinctids of top Oxfordian or basal Kimmeridgian age. Both sets of ammonites have been seen and redetermined by us, and there is no doubt that Arkell's and Spath's determinations and dating were basically correct (in fact, the higher Naifa Cliff ammonites are from the Beckeri Zone at the top of the Tethyan Upper Kimmeridgian, which is approximately equivalent to the top of the north-western European Lower Kimmeridgian). So the Naifa Formation at its type locality at Naifa Cliff extends from the top part of the Oxfordian up to the top of the (Tethyan) Kimmeridgian, and we now have further evidence

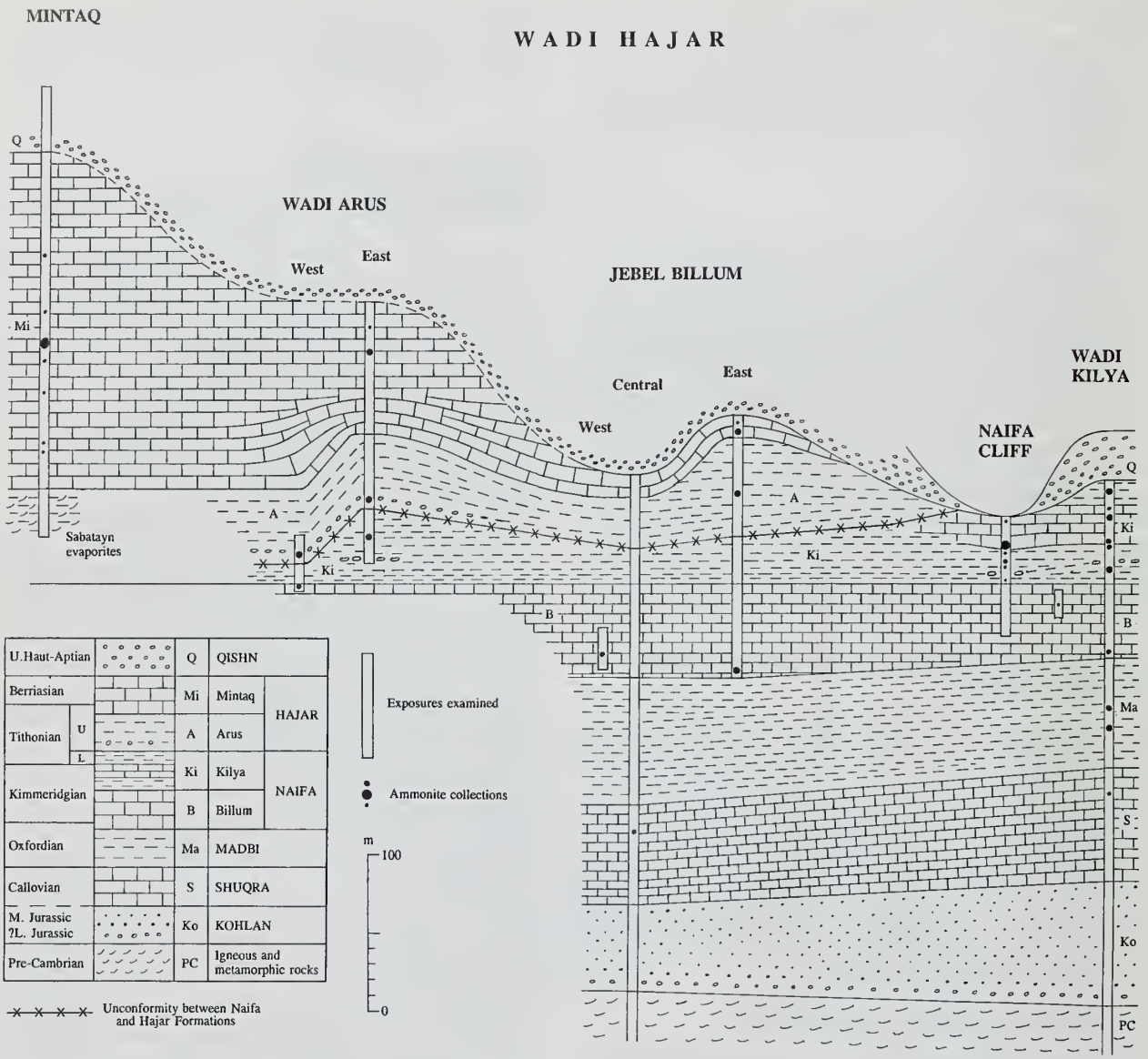


Fig. 2 Correlation of the Jurassic and basal Cretaceous formations in Wadi Hajar.

from Wadi Kilya, near Naifa Cliff, that the youngest beds extend into the basal zone of the Lower Tithonian.

Beydoun traced the Naifa Formation about 15 km north-westwards to the large Jurassic outcrop at Jebel Billum. Here it forms a very striking cliff along the south side of Jebel Billum. Ammonites found by us near the base of the formation near its eastern end, confirm that it is the same age as at Naifa Cliff (though it is truncated at the top by an unconformity, above which are Upper Tithonian marls and limestones of the Hajar Formation).

In Wadi Arus, 10 km north-west of Jebel Billum, there is a very prominent series of thick limestones and interbedded marls, especially well-exposed in the road gorge leading down into the upper end of Wadi Arus from the south-east, which Beydoun correlated with the Naifa Formation because of their great lithological similarity. He found a few poorly preserved ammonites in them, which were tentatively determined by Arkell as probably of Tithonian age. More important, however, was Beydoun's collection of some well-preserved ammonites from the marls and nodules (the 'Breadloaf Concretions') below the thick limestones, and from a few metres of limestone at the base, which are the lowest beds exposed in Wadi Arus. These ammonites were also determined by Arkell as Lower Kimmeridgian, and belong largely to the same species as found at Naifa Cliff. However, because Beydoun thought that the marls and Breadloaf Concretions were below the Naifa Formation, he identified them as the Madbi Formation and the basal few metres of limestone as the top of the Shuqra Formation. These lithological identifications were made despite the complete absence of brachiopods from these beds in Wadi Arus, in marked contrast to the immense numbers of well-preserved brachiopods that occur in the Madbi and Shuqra Formations in both Jebel Billum and the Naifa Cliff/Al Ma'abir area. This is the origin of Beydoun's (1964: 35, 36) records of ammonites from the Shuqra Formation (*Sutneria* aff.

galar (Oppel)) and the Madbi Formation (*Ataxioceras desmoides* Wegele, *Idoceras* cf. *farquharsoni* Spath, *Perisphinctes mombassanus* Dacqué, *P. (Pachysphinctes) robustus* Spath, *P. (Divisosphinctes)* cf. *inaequalis* Spath). In fact, none of these Kimmeridgian ammonites occur in the Shuqra and Madbi Formations, which are of entirely older dates: the basal limestone in Wadi Arus is the top of the Billum Member of the Naifa Formation, and the overlying marls and nodules (the Breadloaf Concretions) belong to the Kilya Member of the same formation and contain the same ammonites as at Naifa Cliff. This part of the succession in Wadi Arus ends at the same unconformity as found at Jebel Billum, that misses out the whole of the Lower Tithonian except for part of the basal zone. It is overlain by more marls (some with gypsum veining), concretions and microbialites[1], containing a splendid ammonite fauna entirely new to Yemen, of basal Upper Tithonian age, then by the massive limestones and interbedded marls that are so obvious in the road gorge leading down into Wadi Arus. Both belong to a new formation (here named the Hajar Formation); the upper massive limestones are largely poor in ammonites here, though a bed full of a new species of Upper Tithonian or basal Berriasian *Substeueroceras* was found in the upper half of the unit.

Another section that is crucial to an understanding of Beydoun's dating of the 'Naifa Formation' is in the Mintaq salt dome. As in Wadi Arus, there are thick massive limestones and interbedded marls in the Mintaq section that were identified as Naifa Formation by Beydoun, though here they are underlain not by marls and concretions, but by evaporites of the Sabatayn Formation. Many microfossils (foraminifera and calpionelids) were obtained from Beydoun's samples from the limestones of the Mintaq section, and they were dated as Upper Tithonian.

For the age of the rocks in Wadi Hajar that he referred to his Naifa Formation, Beydoun now had two incompatible dates: top Oxfordian to Kimmeridgian from the ammonites at Naifa Cliff and Jebel Billum, or Upper Tithonian from the microfossils at Mintaq and the meagre evidence in Wadi Arus. He chose the Upper Tithonian date from the Mintaq evidence. This was unfortunate, because the limestones at Mintaq and the upper limestones at Wadi Arus are not the same as those at Naifa Cliff/Al Ma'abir and Jebel Billum, and Upper Tithonian is a whole stage too high for the date of the Naifa Formation at its type locality in Naifa Cliff.

One final section to be considered is that at Jebel Madbi. Though we have not seen it ourselves, from Beydoun's detailed section and from subsequent photographs, it can be interpreted according to the nomenclature used by Beydoun himself at Naifa Cliff and Jebel Billum. The position of the base of the marly Madbi Formation is clear in Jebel Madbi, and this is its type locality. After a thickness of 100 m of marls, there are 74 m of limestones, then 78 m of more marly limestones, before a return to massive limestones, conglomeratic at the base, which attain the very large thickness of 434 m in Jebel Madbi. Because of the prominence of the latter limestones with conglomerates at their base, Beydoun identified them as the Naifa Formation, which made his underlying Madbi Formation 252 m thick, including the 74 m thick sequence of limestones in the middle. In fact, the latter limestones on Jebel Madbi are the lower half of the Naifa Formation (the Billum Member), the next 78 m of more marly limestones are the upper half the of same formation (the Kilya Member, exactly as at Naifa Cliff and in Wadi Kilya), and the overlying 434 m of conglomerates and massive limestones are the Hajar Formation, with the conglomerates at the base marking the unconformity.

[1]Calcareous bodies formed by algae, bacteria and cyanobacteria; they include stromatolites, thrombolites and dendrolites.

Table 1 Comparison of the lithological nomenclature for the Jurassic and basal Cretaceous in Wadi Hajar as proposed by Beydoun in 1964–68 and as used subsequently. In the left hand column N shows the range of the limestones at the type locality of the Naifa Formation at Naifa Cliff and close vicinity, while M shows the range of the limestones in the Mintaq Salt Dome.

BEYDOUN 1964-68	SUBSEQUENT INTERPRETATIONS		THIS PAPER	
Formation	Formation	Member	Formation	Member
M — NAIFA — N	NAIFA		HAJAR	Mintaq
				Arus
	MADBI	U. Madbi Shales	NAIFA	Kilya
		Madbi Porcellanites		Billum
MADBI		L. Madbi Shales	MADBI	
SHUQRA	SHUQRA		SHUQRA	
KOHLAN	KOHLAN		KOHLAN	

Beydoun's incorrect correlation between Naifa Cliff/Jebel Billum and Wadi Arus/Mintaq/Jebel Madbi has had profound effects on all later work. From the obvious lithological divisions in a section like Jebel Madbi, the terms Lower Madbi Shales (for the whole of the real Madbi Formation), Madbi Porcellanites (for the Billum Member of the Naifa Formation), Upper Madbi Shales (for the Kilya Member of the Naifa Formation), and 'Naifa Formation' (for the Hajar Formation as proposed here) have become widely used in recent years (see Table 1). Thus the term 'Naifa Formation' has been transferred to rocks of Upper Tithonian and Berriasian age. This has been done despite the fact that as a consequence there is no such 'Naifa Formation' at its type locality at Naifa Cliff. If lithostratigraphical nomenclature is to be used in a meaningful and practical way, then notice has to be taken of priority of usage and the rocks that occur at type sections, because to contend that a formation does not occur at its type locality leads to unacceptable instability of nomenclature. So the Naifa Formation is used here as originally defined from the rocks that occur at its type locality at Naifa Cliff and the immediate vicinity. Also the base of the Madbi Formation is drawn where it was first proposed at the base of the argillaceous formation in Jebel Madbi; it is about 100 m thick and extends as far up as the base of the overlying limestones, which are the same as the limestones of the Naifa Formation as defined at Naifa Cliff. On Jebel Madbi the Naifa Formation consists of a lower half of about 74 m of limestones, and an upper half of about 78 m of more marly limestones, up to the unconformity overlain by conglomerates and limestones of the Hajar Formation.

In his original definition in the Naifa Cliff/Al Ma'abir area (which includes Wadi Kilya), Beydoun was quite clear that the Naifa Formation consists of a lower limestone half, overlain by a more marly upper half, which we now call the Billum and Kilya Members respectively. The Kilya Member is terminated by an obvious unconformity in Wadi Arus, where it is followed by the Hajar Formation, with marls, limestones and concretions at the base (here named the Arus Member), then by thick massive limestones above. The latter limestones are prominent and thick at Mintaq, where they are here named the Mintaq Member of the Hajar Formation. The whole succession appears to attain its thickest, and perhaps most complete, development on Jebel Madbi, which would repay careful investigation and ammonite collecting. Beydoun's interpretation of

Table 2 Ammonite zones of the Callovian to Berriasian Stages in the Tethyan Province, and dates of the formations in Wadi Hajar (zones in the Callovian and Oxfordian Stages are based on Arkell (1956), Mouterde & Enay (1971: 16–21) and Cariou & Hantzpergue (1997: 80, 84, 362), those in the Kimmeridgian to Berriasian Stages on Howarth (1992: 599–601)). The horizons of dateable ammonite faunas in Yemen are shown by asterisks (*).

STAGES		AMMONITE ZONES	MEMBERS	FORMATIONS
BERRIASIAN		*Fauriella boissieri* *Tirnovella occitanica* *Pseudosubplanites euxinus*	* Mintaq *	HAJAR
TITHONIAN	U	*Durangites* *Micracanthoceras microcanthum*	* * Arus	
	L	*Micracanthoceras ponti* *Semiformiceras fallauxi* *Semiformiceras semiforme* *Neochetoceras darwini* *Hybonoticeras hybonotum*	Disconformity/unconformity	
KIMMERIDGIAN	U	*Hybonoticeras beckeri* *Aulacostephanus eudoxus* *Aspidoceras acanthicum*	* Kilya *	NAIFA
	L	*Crussoliceras divisum* *Ataxioceras hypselocyclum* *Sutneria platynota*	* Billum	
OXFORDIAN	U	*Subnebrodites planula* *Epipeltoceras bimammatum* *Dichotomoceras bifurcatum*	*	
	M	*Gregoryceras transversarium* *Perisphinctes plicatilis*		* MADBI
	L	*Cardioceras cordatum* *Quenstedtoceras mariae*		*
CALLOVIAN	U	*Quenstedtoceras lamberti* *Peltoceras athleta*		
	M	*Erymnoceras coronatum* *Reineckeia anceps*		* SHUQRA
	L	*Sigaloceras calloviense* *Proplanulites koenigi* *Macrocephalites herveyi*		
BATHONIAN				KOHLAN

the Jebel Madbi section, with the limestone sequence (the Billum Member) sandwiched between two marl sequences, led to the proposal of the term Timurah Member in the explanation of the Bir Ali/Balhaf map (D-39-61/73) for the development of this middle limestone (the Billum Member) in the area around Jebel Timurah and Wadi Timurah, approximately half way between Jebel Madbi and Jebel Billum. We have not seen the type section or a formal description of the Timurah Member, so we do not adopt this term in preference to Billum Member.

LOCALITIES IN WADI HAJAR

Fig. 1 shows the location of Wadi Hajar and the main geological sections examined in relation to Mukalla and the surrounding area in southern Yemen, and also a more detailed map of the area in Wadi Hajar between Al Ma'abir and Wadi Arus. The series of formations and members in the Jurassic and Lower Cretaceous of Wadi Hajar that are recognized here are shown in the right hand column of Table 1. Of these, the Hajar Formation and its two members, and the two members of the Naifa Formation, are newly proposed in this paper. A general distribution and correlation diagram for the Jurassic and

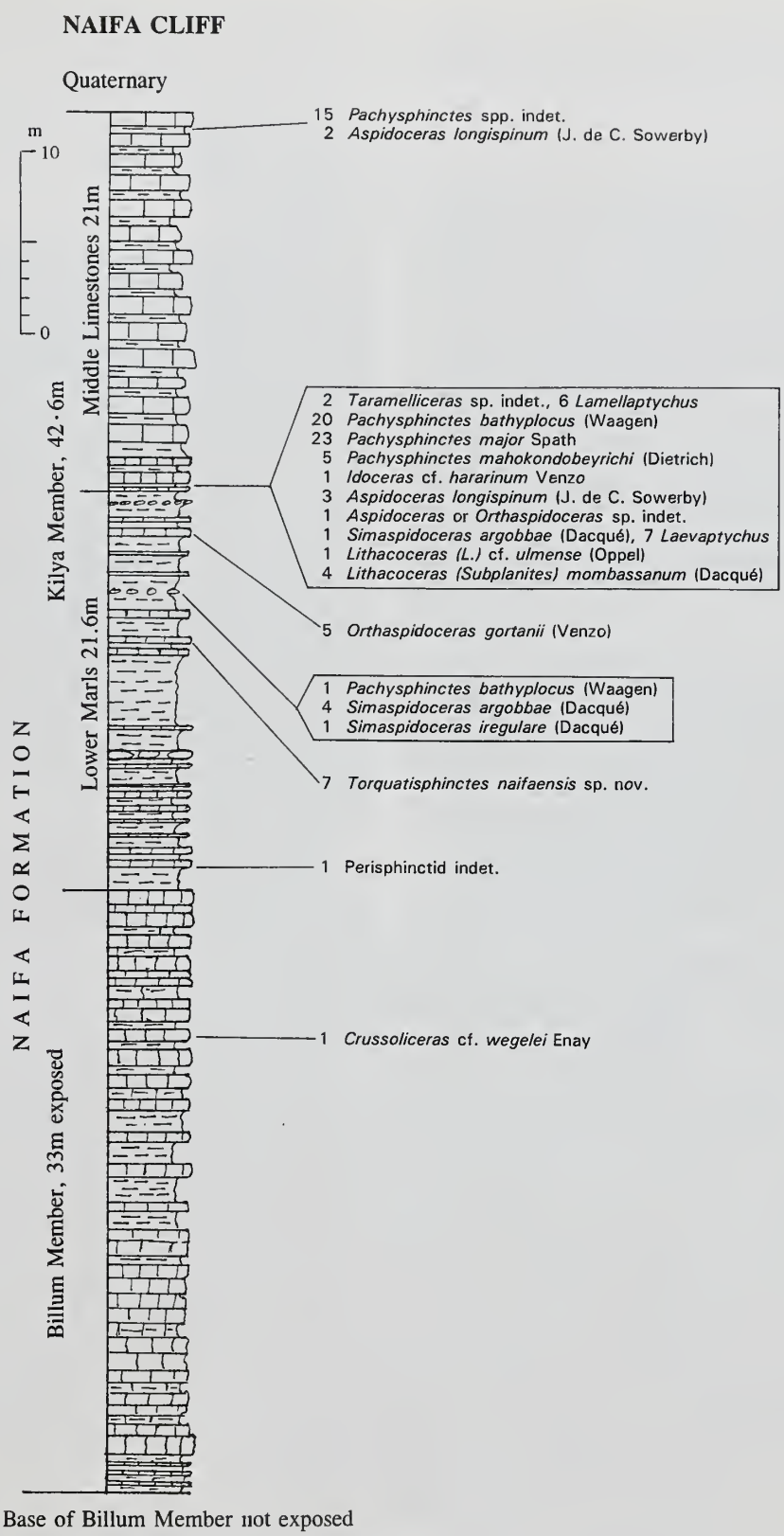


Fig. 3 Vertical section of the Naifa Formation at Naifa Cliff on the southern (right) bank of the river.

lowest Cretaceous in Wadi Hajar is given in Fig. 2, and a scheme of zones for the Callovian to Berriasian stages showing the positions of the dateable ammonite faunas in the Wadi Hajar succession, is given in Table 2.

Naifa Cliff

The splendid cliff section in the right bank of the river below the village of Naifa (=Neifa, Nayfa and Nayfah), approximately 2 km upstream from the road/river crossing at Al Ma'abir, is the type section of the Naifa Formation (see Fig. 9). The base of the Billum Member is not exposed in this cliff, but it is clear in the nearby locality south of Wadi Kilya (see below, and Fig. 5) and is also exposed immediately west of the road/river crossing at Al Ma'abir. In Naifa Cliff 33 m of alternating limestones and marly limestones of the Billum Member, in which no ammonites were found, are followed by the Kilya Member, which consists of 21.6 m of marls with subsidiary limestones in its lower part, then 21 m of thicker limestones in the upper part (Fig. 3). The upper marly part of the Kilya Member is missing at Naifa Cliff, where the highest horizon is near the top of the middle limestone part (as compared with the thicker development of the Kilya Member in Wadi Kilya), and the eroded top is overlain by Quaternary river gravels. The 'oil shales' of Little (1925: pl. 24) are probably at the base of the Kilya Member on Fig. 3. Considerable numbers of ammonites (mainly large perisphinctids) were found loose at the foot of the cliff, and they were traced to a mid-brown-weathering limestone near the bottom of the middle limestone part of the Kilya Member, as shown on Fig. 3. Some of the perisphinctids attain sizes larger than 250 mm diameter, and two exceptionally large (400–500 mm diameter) specimens of *Idoceras* cf. *hararinum* Venzo were seen, one of which was collected. Below this horizon of prolific ammonites, ammonites were collected from three other horizons. The upper one has body-chambers of *Orthaspidoceras gortani* (Venzo), the middle one has large examples of two species of *Simaspidoceras* preserved in grey limestone, while the lowest horizon has a new species of *Torquatisphinctes* (Fig. 3). The highest ammonites in Naifa Cliff are crushed specimens from a shell bed high in the middle limestones of the Kilya Member. All these ammonites belong to the Beckeri Zone of the (Tethyan) Upper Kimmeridgian. The single example of the Lower Kimmeridgian, Divisum Zone, ammonite *Crussoliceras* cf. *wegelei* Enay shown on Fig. 3 was collected from the upper part of the Billum Member in a nearby new road cutting, 0.5 km east of the road/river crossing at Al Ma'abir.

Wadi Kilya

This section through the Naifa Formation lies on the south side of the hill that is capped by the Qishn Formation on the south side of Wadi Kilya, 2.5 km E by S of Naifa Cliff (Fig. 4). The Kilya Member is thick and well-exposed here, being subdivided into three horizons. The lower marly horizon and the middle limestone horizon are both thicker than at Naifa Cliff, and are followed by a return to marls and thin limestones in an upper horizon (Fig. 5). The middle limestones contain many of the same perisphinctids and aspidoceratid ammonites as found in Naifa Cliff, while the lower marly horizon contains an horizon rich in crushed *Lithacoceras* and *Orthaspidoceras*. The section also extends to an upper marly horizon in the Kilya Member, which is at a higher horizon than the truncated top of Naifa Cliff. These upper marls are 15 m thick, and contain a bed with the best preserved ammonites in Wadi Hajar, especially *Katroliceras*, and species of *Hybonoticeras* that are distinctive of the Lower Tithonian, Hybonotum Zone. They are overlain unconformably by the Qishn Formation of Upper Hauterivian to Barremian age. To the south of the main section there is a long cliff exposure of the Billum Member, with a good basal contact with the shales of the Madbi Formation. The Billum Member limestones are 48 m thick here, and crushed *Orthosphinctes polygyratus* (Reinecke) and other ammonites distinctive of the Upper Oxfordian, Bimammatum Zone, were collected from the basal few metres.

The Kohlan, Shuqra and Madbi Formations were also examined in the area about 1 km south of Wadi Kilya and 1–1.5 km SE of the road/river crossing at Al Ma'abir. Detailed logs were made here of the Kohlan and lower and middle parts of the Shuqra Formations,

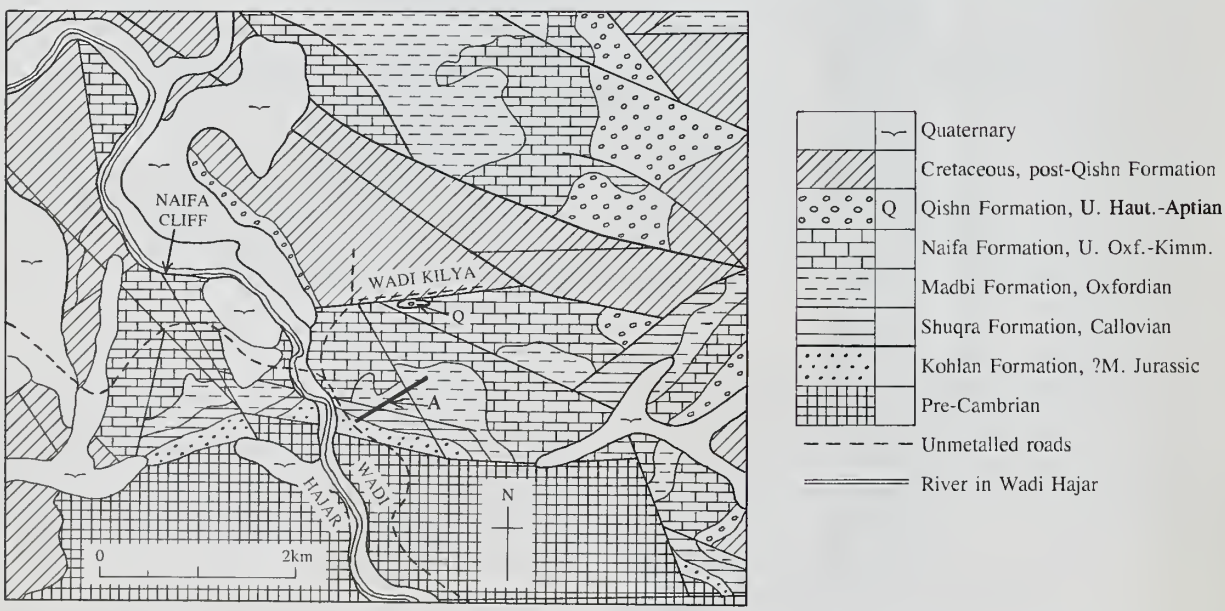


Fig. 4 Geological map of the area around Al Ma'abir, Naifa Cliff and Wadi Kilya. The Wadi Kilya section of Fig. 5 is on the southern side of the Qishn Formation capped hill on the south side of Wadi Kilya. The section through the top Kohlan, Shuqra and Madbi Formations is at A south of Wadi Kilya.

and many brachiopods, bivalves and gastropods were obtained from the Shuqra and Madbi Formations (Fig. 6).

Jebel Billum

The long arcuate outcrop of sedimentary Jurassic rocks at Jebel Billum is about 10 km long. It overlies Precambrian metamorphic and igneous rocks (and basalts that are probably Lower/Middle Jurassic in age) to the south-west, and is followed by the Qishn Formation, then higher Cretaceous rocks and massive Tertiary limestones to the north-east (Fig. 7). The peak of Jebel Billum itself is formed by Palaeocene limestones of the Umm-er-Radhuma Formation. In the north-western part of the outcrop, a cliff in the upper part of the Jurassic (Fig. 8) lies south-west of that peak. Here the Naifa and Hajar Formations are overlain by the Qishn Formation, the contact with the latter being readily recognizable by the sharp colour change from grey to reddish-brown near the top of the cliff. The top of the Madbi Formation occurs at the base of the cliff, and the overlying Billum Member is 60 m thick, extending up to a prominent white limestone (Fig. 10). The Kilya Member has a middle limestone section between more marly beds above and below, as at Wadi Kilya, but the exact position of the disconformable contact with the Arus Member is uncertain owing to lack of access. It is at or some distance below the prominent beds of massive grey limestone near the top of the cliff which are overlain by the more sandy reddish-brown beds of the Qishn Formation. The lower Billum Member part of this cliff extends westwards to the road-cutting at the western entrance to the Jebel Billum inlier, where it forms an overhanging cliff, which was the vantage point for the photograph of Fig. 8 (also Beydoun's (1964: pl. 9, lower) photograph; note that on his photograph he placed the 'Naifa'/Qishn 'unconformity' at the position of the Billum/Kilya Member contact). The *Glochiceras* and *Orthosphinctes* shown in the bottom half of the Billum Member in Fig. 12 were collected from material excavated from this western road-cutting entrance to Jebel Billum.

From the front of Jebel Billum, the cliff of Naifa and Hajar Formations extends south-eastwards for several kilometres forming long cliffs, near the top of which the Qishn contact is readily seen from the sharp colour change to reddish-brown. The unconformity between Naifa and Hajar Formations (ie. at the contact between the Kilya Member and the Arus Member) is also well seen, especially in the long easternmost cliff. At the base of this cliff near its eastern end (Fig. 11; at locality PC on Fig. 7) many perisphinctids occur 7–8 m above the base of the Billum Member. Many are fragments or moulds of large specimens on limestone blocks and are neither well-preserved nor collectable. Several photographs and some specimens were obtained (list on Fig. 12), and they form the main evidence for the dating of the bottom of the Billum Member as Upper Oxfordian.

A succession that is more difficult to interpret is in a steep bank and cliff on the north side of the road just before it leaves the eastern end of the Jebel Billum outcrop (locality EJB on Fig. 7). The *Orbitolina* Limestone of the Qishn Formation forms a small cliff at the top of the bank, and parts of the underlying Arus Member are exposed in the bank below, including the contact with the Kilya Member, which can be clearly seen to be an unconformity here. The bulk of the Kilya Member is obscured, but at the western end of the outcrop the whole thickness of the Billum Member is well seen. The main interest, however, is in the Arus Member, which is 61.5 m thick here, and in the 13.8 m of the Mintaq Member up to the disconformity at the base of the Qishn Formation (Fig. 12). The Mintaq Member has two horizons with ammonites: an upper bed of marls only 5 m below the Qishn with crushed *Substeueroceras*, and a lower bed of porcellanous limestones with many ammonites including *Virgatosphinctes, Choicensisphinctes, Substeueroceras* and *Blanfordiceras*. Both faunas are from the upper half of the Upper Tithonian, and the upper one is important in providing evidence for the age of the beds immediately below the Qishn Formation in Jebel Billum. The underlying shales and marls of the Arus Member contain similar ammonites in a bed of rubbly limestone just below the middle of the member (Fig. 12), and the age is somewhat lower in the Upper Tithonian. A single specimen of *Crioceratites* from the basal bed of the Qishn Formation here is the first evidence for an Upper Hauterivian date for the bottom of that formation. No ammonites were found in the Kilya Member at this locality, nor have they been found anywhere else in the Jebel Billum inlier, though there are large areas of outcrop where they might be expected, all of which are difficult to reach (eg. the flanks of the main Jurassic cliff in Figs 8, 10).

The Kohlan, Shuqra and Madbi Formations are well exposed in the valley (part of Wadi Ghiadhat) below the main Jurassic cliff in Jebel Billum, and there are places where the contact with the metamorphosed basement igneous rocks is seen. The upper half of the Shuqra and the Madbi Formations were measured here, and large collections were made of the immensely rich brachiopod faunas. Bivalves and gastropods are also abundant at some horizons, and there is a bed containing large specimens of the nautiloid *Paracenoceras* near the top of the Shuqra Formation (Fig. 6).

Wadi Arus

4 km west of the western road entrance to the Jebel Billum inlier the road descends into the upper end of Wadi Arus through a gorge that exposes the full thickness of the Mintaq Member of the Hajar Formation (Fig. 7). At the bottom the road turns northwards into the wider part of Wadi Arus and after 1 km passes a prominent cliff on the west exposing a bed of large microbialite boulders near the top (Figs 13, 15). There are cliffs on both sides of the wadi here, and correlation between them poses difficulties, though it appears that the lowest limestone in the eastern cliff can be traced continuously across the wadi and the unmetalled road to the middle of the western cliff (Fig. 16). A short distance to the north a complex low-angle fault system brings the Cretaceous down to the bottom of the wadi and the Jurassic is not seen again farther north. Little visited this locality and published vertical sections of the western cliffs (Little, 1925: pl. 25) showing the fault and beds up the wadi to the south, though it is not possible to identify the cliff with the microbialite boulders on his sections. He also gave a section (1925: pl. 26) of the eastern cliffs, marking a bed of 'oil shales', which he said correlated with a similar bed at Naifa Cliff. This is near the bottom of the lowest exposure in the eastern cliffs shown on Fig. 16, and being near the base of the Kilya Member, Little's correlation is nearly correct. Beydoun also visited these exposures, and collected ammonites from the Breadloaf Concretions on the east side (which he said belonged to the Madbi Formation) and also a few from the top of the Billum Member (which he said was part of the Shuqra Formation) (Beydoun, 1964: 35, 36), but he made no reference to the bed of large microbialite boulders in the western cliff.

The upper part of the Billum Member is seen in a small cliff just south of that west cliff (Fig. 13, lower left), and its top bed containing many crushed impressions of *Streblites* and perisphinctids forms the pavement at the bottom of the main cliff (Fig. 15). In the west cliff there is a thickness 12.4 m of pale grey marls and limestones of the Kilya Member up to a clear disconformity at the base of the Arus Member of the Hajar Formation. The bottom bed of the Arus Member consists of darker yellow-brown marls and limestones containing many strings and cross-bedded veins of gypsum, as well as scattered microbialite boulders. On the south side of the western

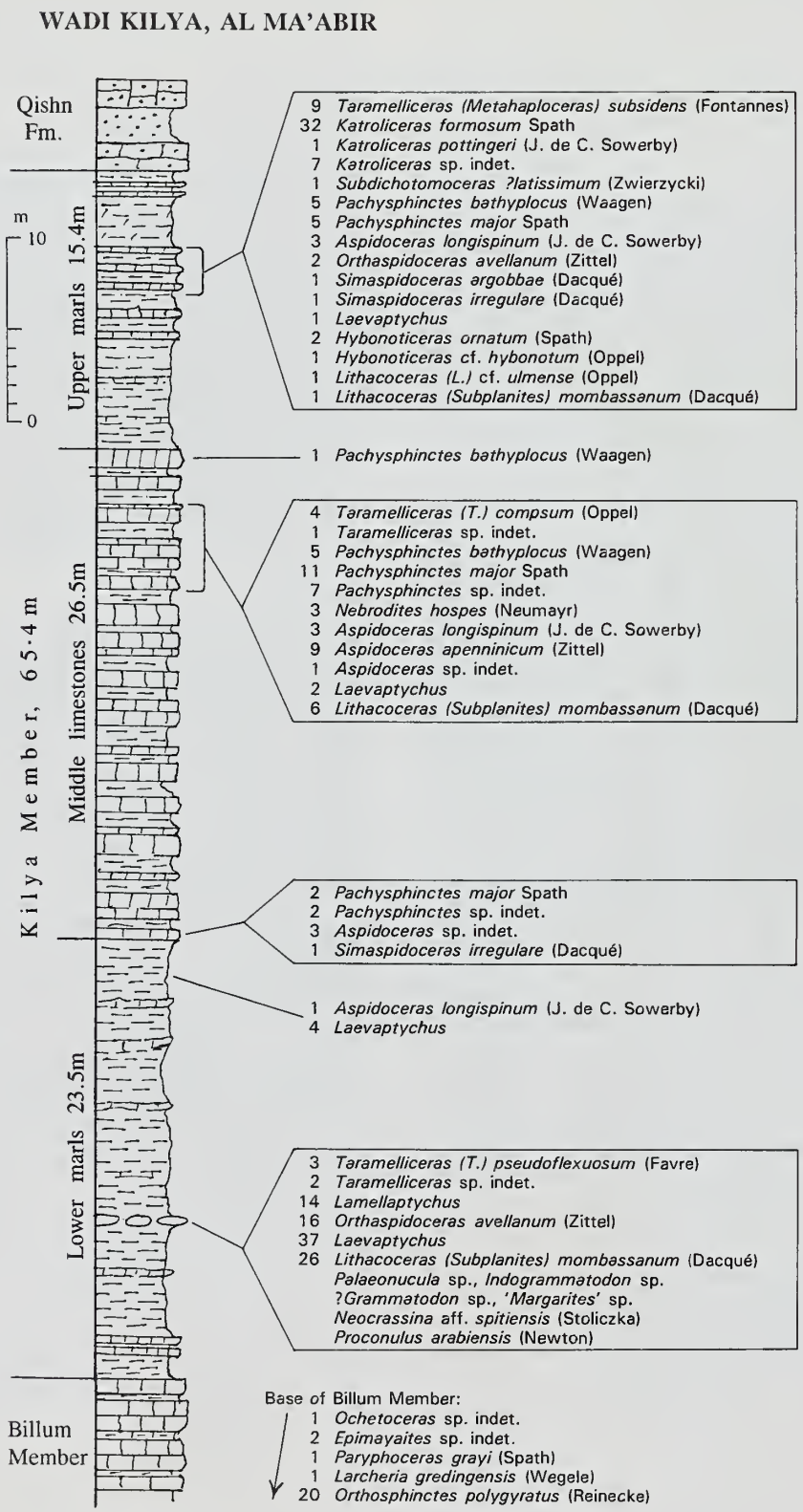


Fig. 5 Vertical section of the Naifa Formation at Wadi Kilya, Al Ma'abir (see Fig. 4 for location).

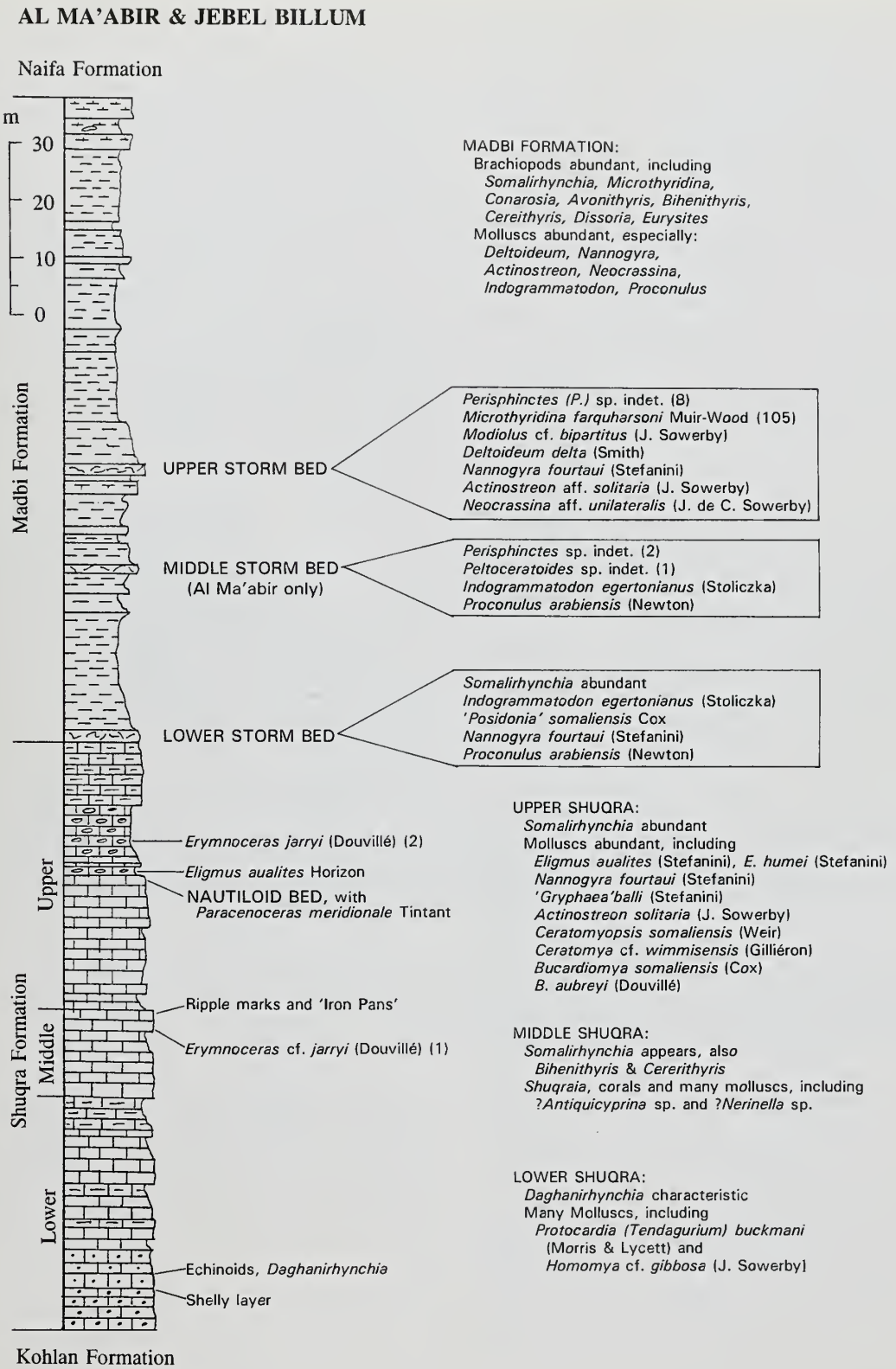


Fig. 6 Vertical section of the Shuqra and Madbi Formations in central Jebel Billum and from 0.6 km SE of the Al Ma'abir road/river crossing to 1 km eastwards; thicknesses of the Madbi and the Upper Shuqra are taken from the Jebel Billum section, while thicknesses of the Middle and Lower Shuqra are taken from the Al Ma'abir area; the Madbi Formation below the Middle Storm Bed is faulted out at Al Ma'abir.

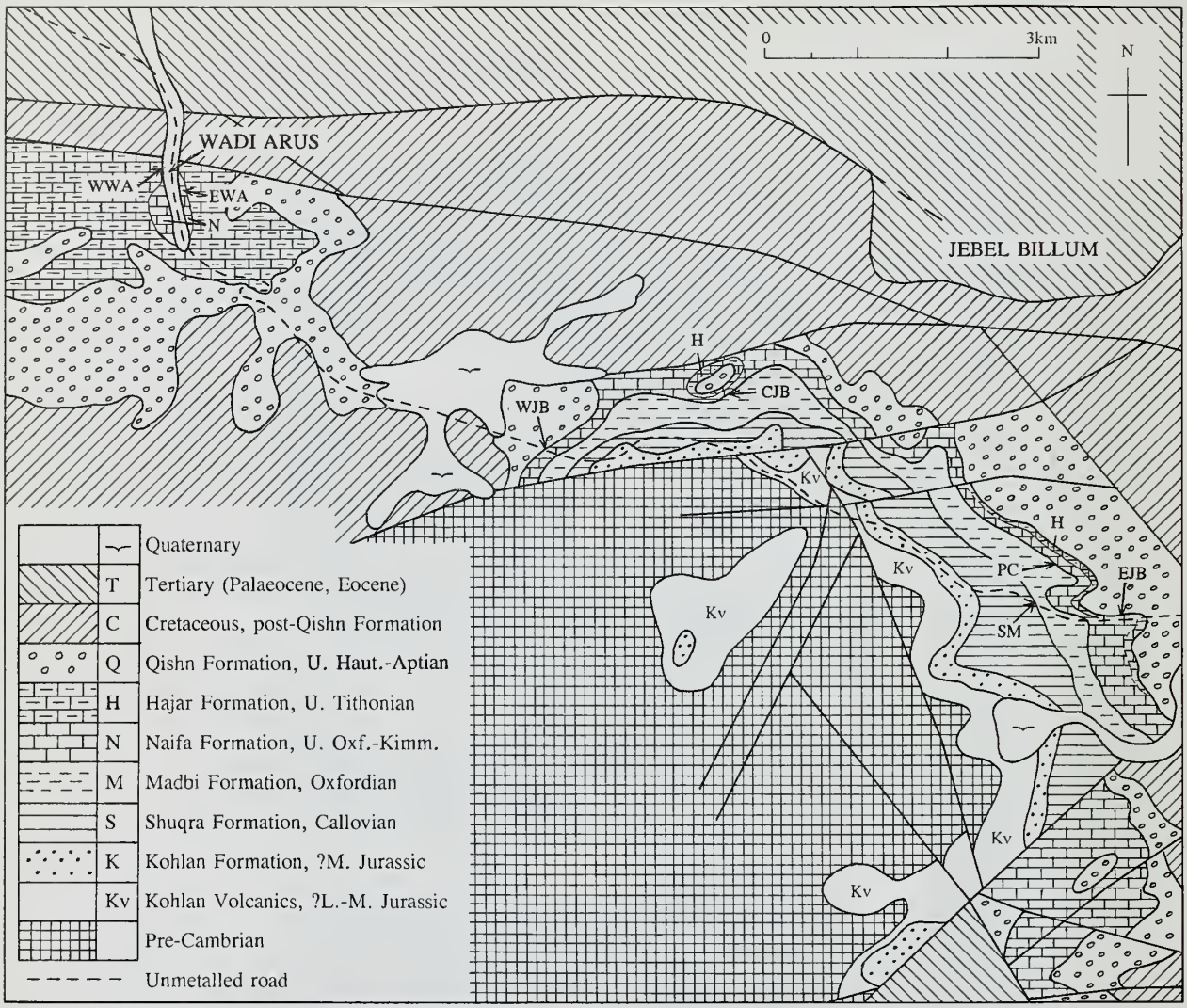


Fig. 7 Geological map of Jebel Billum and Wadi Arus. **EWA** and **WWA** are the locations of the east and west cliffs in Wadi Arus of Figs 13, 15, 16; **WJB** is the western road entrance to Jebel Billum; **CJB** is the main Jurassic cliff section of central Jebel Billum, photographed from the western entrance in Fig. 8, and in detail in Fig. 10; **PC** (Perisphinctid Cliff) is the long cliff (shown in Fig. 11) with perisphinctids low in the Billum Member at its base; **EJB** (Eastern Jebel Billum) is the section on the north side of the road where it first enters eastern Jebel Billum, depicted in the upper half of Fig. 12; **SM** is the exposure of the Shuqra and Madbi Formations in east Jebel Billum, 1 km SW of the Perisphinctid Cliff.

cliff access can be gained to the Kilya/Arus contact, where it is seen to be an angular unconformity, the irregular bottom of the Arus Member cutting down into the eroded top of the Kilya Member. Access can also be obtained here to the scattered boulders in this bottom bed and to the main 2.4 m thick bed of boulders. A rich basal Upper Tithonian ammonite fauna was obtained from these boulders (Fig. 17), mainly from 2.4 m bed of large microbialite boulders, but the same ammonites also occur in the smaller boulders that are scattered through the bed below down to the base of the Arus Member. The whole ammonite fauna is new to Yemen, and includes the remarkable discovery of two large examples of the boreal ammonite *Riasanites rjasanensis* (Lahusen), the only record of this genus in the Tethyan Province except in Argentina, and at a considerably older horizon than its topmost Tithonian to Berriasian age in the Boreal Province. Beds have apparently slumped and slipped along low angle planes at the top of this west cliff, and it is not clear how much (if any) of the Mintaq Member is present higher up before Cretaceous rocks are emplaced (?by slumping).

The succession in the eastern cliff is considerably different: the two points of correlation are the bed of microbialite boulders, which are clearly the same on both sides of the wadi, and the limestone that is the lowest horizon exposed on the eastern side (Fig. 16). Above the latter limestone there are 35 m of marls and limestones of the Kilya Member up to the base of the Arus, which are not seen in the west side cliff, having been cut out by sliding, slumping or erosion. Near the middle of the Kilya Member as developed in this eastern cliff there are marls containing the Breadloaf Concretions, from which a rich Upper Kimmeridgian, Beckeri Zone, ammonite fauna was collected. It is similar to the fauna from the lower part of the Kilya Member in Wadi Kilya and at Naifa Cliff. In fact, 2.5 m above the base of the Kilya Member in the eastern cliff there is an horizon of widely scattered, large (1 m diameter × 0.5 m thick) grey limestone

doggers, which are so similar to the large doggers 7.5 m above the base of the Kilya Member in Naifa Cliff (Fig. 3), that a direct lithological correlation between them might be postulated. The microbialite boulders in the eastern cliff contain the same ammonites as in the boulders of the west cliff, and above them are 40.9 m of marls and limestones before much more massive limestones are reached that mark the base of the Mintaq Member. These can be traced continuously along the cliff to the south, then up the road gorge out of the wadi to the south-east up to the base of the Qishn Formation, making a total thickness of 85 m of Mintaq Member (Fig. 18). There are huge slumped blocks of these Mintaq Member limestones on the south side of the road gorge, especially at its lower end where it turns into the wadi, which are seen in a photograph published by Beydoun (1964: pl. 11). Most of the limestones contain no ammonites (or other fossils), but about 31 m below the top there is a bed containing abundant crushed *Substeueroceras* and a few *Protacanthodiscus*, which give an Upper Tithonian or basal Berriasian age to this part of the Mintaq Formation. Still higher, about 16 m below the Qishn Formation, a very large (0.5 m diameter) *Aspidoceras* was seen and photographed, though it could not be collected.

The Mintaq Salt Dome

About 50 km farther up Wadi Hajar to the north-west is an area where Jurassic rocks outcrop in three small salt domes. The first of these is the Mintaq Salt Dome, 8 km beyond Sidara, in which the Mintaq Member has been pushed into an orientation with vertical bedding around the periphery of the dome, by rising gypsum and halite deposits in the underlying Sabatayn Formation. There are two main outcrops of the Mintaq Member here, the south-western and north-eastern outcrops, separated by the core of the dome in which there are two plugs of Recent basalts (Fig. 19). The south-western outcrop gives a continuous measurable succession from its contact with the Sabatayn evaporites, through 215.7 m of limestones with subsidiary marls, up to its contact with the overlying Qishn Formation, where a disconformity misses out part of the Berriasian, the Valanginian, and Lower Hauterivian stages (Fig. 20). The upper two-thirds of the Mintaq Member and its contact with the Qishn Formation are well exposed in a gulley (Fig. 14; at locality X on Fig. 19), near the bottom end of which a rich ammonite fauna was collected from beds 27–77. A few ammonites occur sporadically in higher and lower beds. All are new to Yemen and are of mid-Berriasian age. Of particular interest is the abundance of the Tethyan ammonite *Spiticeras* and the South American Berriasian genus *Argentiniceras*. There are no ammonites in the top 64 m of the Mintaq Member, the age of which, though probably still Berriasian, is not known accurately. The ammonite-bearing beds were not located on the hillside east of the main gulley (Fig. 14, background at top right), nor were they located during a search of the extensive north-eastern outcrop of the Mintaq Member in the salt dome. The latter outcrop appears to expose the same beds as in the south-western outcrop, and there are large areas of exposure of vertical or slightly overturned beds on a high 1 km long NW-SE trending ridge, up to a contact with a small area of Qishn Formation.

LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

The Kohlan Formation

LITHOLOGY AND TYPE SECTION. The term Kohlan Formation was first used by Beydoun (1964: 31), being derived from the 'Kohlan Series' of Lamare (1930: 52), which was proposed for the arenaceous beds at the base of the Jurassic on the high plateau at Kohlan, 75 km NW of Sana'a. At that type locality the formation consists of about 250 m of conglomerates, sandstones and sandy marls, with plant impressions in the top 30 m. Beydoun (1968: 64) took the section about 1 km SE of the river crossing at Al Ma'abir as the reference section and location for the Kohlan Formation in Wadi Hajar, where it is about 55 m thick and lies directly on eroded and peneplaned basement rocks. At the top it is overlain conformably by the Shuqra Formation, the base of which is placed at the bottom of the lowest bed of calcified sandstone that shows evidence of marine conditions, bioturbation and contains some shelly layers. The Kohlan Formation is also well exposed in the central part of the Jebel Billum inlier, and a photograph of its contact with the Precambrian basement was given by Beydoun (1964: 44, pl. 8, upper figure). According to the German Geological Map (explanation of sheet D-39-61/73) the basal sedimentary Jurassic rocks in the Jebel Billum inlier are underlain by tuffs and basalt and trachyte lavas, that are themselves of Jurassic age. The evidence for the Jurassic (rather than Precambrian) age of these igneous rocks is not known to us.

At both Al Ma'abir and Jebel Billum the Kohlan Formation consists of coarse-grained sandstones, pebble beds and conglomerates, with a few horizons of finer silts and silty marls in the upper part. The conglomerates contain many boulders and pebbles of the basement beds, cross-bedding is frequent, some beds are cut by quartz seams, and there are haemetite cemented patches in the upper beds. The formation is probably fluviatile or estuarine throughout.

BIOSTRATIGRAPHY. There is no fossil evidence for the date of the Kohlan Formation in Wadi Hajar or most other areas of Yemen. In the Dhufar region of Oman, immediately east of Yemen, the occurrence of a fossil plant low in the formation suggests that it might be of Lower Jurassic age at that level (Beydoun, 1964: 46; 1968: 65). The date of the top of the formation is delimited by the age of the base of the overlying Shuqra Formation, and the only new evidence we have to add is the occurrence of three species of echinoids near the base of the Shuqra. These and the abundant faunas of *Daghanirhynchia* immediately above, are Bathonian or Lower Callovian in age, which suggests that the top of the Kohlan Formation might lie within the Bathonian.

The Shuqra Formation

LITHOLOGY AND TYPE SECTION. After the earlier use of the term 'Shuqra Limestone', the name Shuqra Formation was first used by Beydoun (1964: 31–35; 1968: 105–07) for a calcareous formation above the arenaceous Kohlan Formation and below the argillaceous Madbi Formation. The type locality is at Jebel Urays, 15 km north of Shuqra, and 80 km north-east of Aden, where it follows the Kohlan Formation unconformably, and consists of 98 m of limestones, truncated at the top by Tertiary basalts.

The Shuqra Formation is well exposed in the wadi below the main Jurassic cliff in central Jebel Billum, where it is conformable with both the Kohlan Formation below and the Madbi Formation above, and is about 100 m thick. At Al Ma'abir the Shuqra Formation occurs 1 km south-east of the river crossing, and is about 70 m thick, where it follows the Kohlan Formation conformably, but the upper part is only partly exposed and the contact with the Madbi is faulted.

The Shuqra Formation is calcareous throughout, though the limestones are nodular, rubbly or marly at some horizons, and it is sandy in the lower part, where the basal beds are transitional from the Kohlan Formation. The middle part is more heavily calcified and has more massive, fine-grained limestones. At the top it ends with a bed with ripple marks then a ferruginous surface at Al Ma'abir and two

Fig. 8 The main Jurassic cliff, central Jebel Billum; the peak of Jebel Billum consists of Palaeocene Limestone of the Umm-er-Radhuma Formation; the vertical cliff in the foreground is formed by the Naifa and Hajar Formations, and is capped by the Qishn Formation (see Fig. 10 for detail).

Fig. 9 The type locality of the Naifa Formation at Naifa Cliff; most of the beds are the middle and upper parts of the Billum Member; the Kilya Member is the highest cliff in shadow on the extreme right.

Fig. 10 Detail of the main Jurassic cliff (at CJB on Fig. 7) on the southern side of Jebel Billum; owing to the difficulty of access, the exact position of the unconformity between the Kilya and Arus Members is uncertain.

Fig. 11 The Perisphinctid Cliff in eastern Jebel Billum (at PC on Fig. 7); most of the cliff consists of Naifa and Hajar Formations overlain by Qishn Formation at the top; Madbi Formation is exposed at the base of the cliff on the left, and perisphinctid ammonites occur low in the Billum member at the base of the cliff in the centre of the photograph.


Qishn
Arus
Kilya
Billum
Madbi
Shuqra
Qishn
Arus
Kilya
Billum
Madbi
Shuqra

10

11

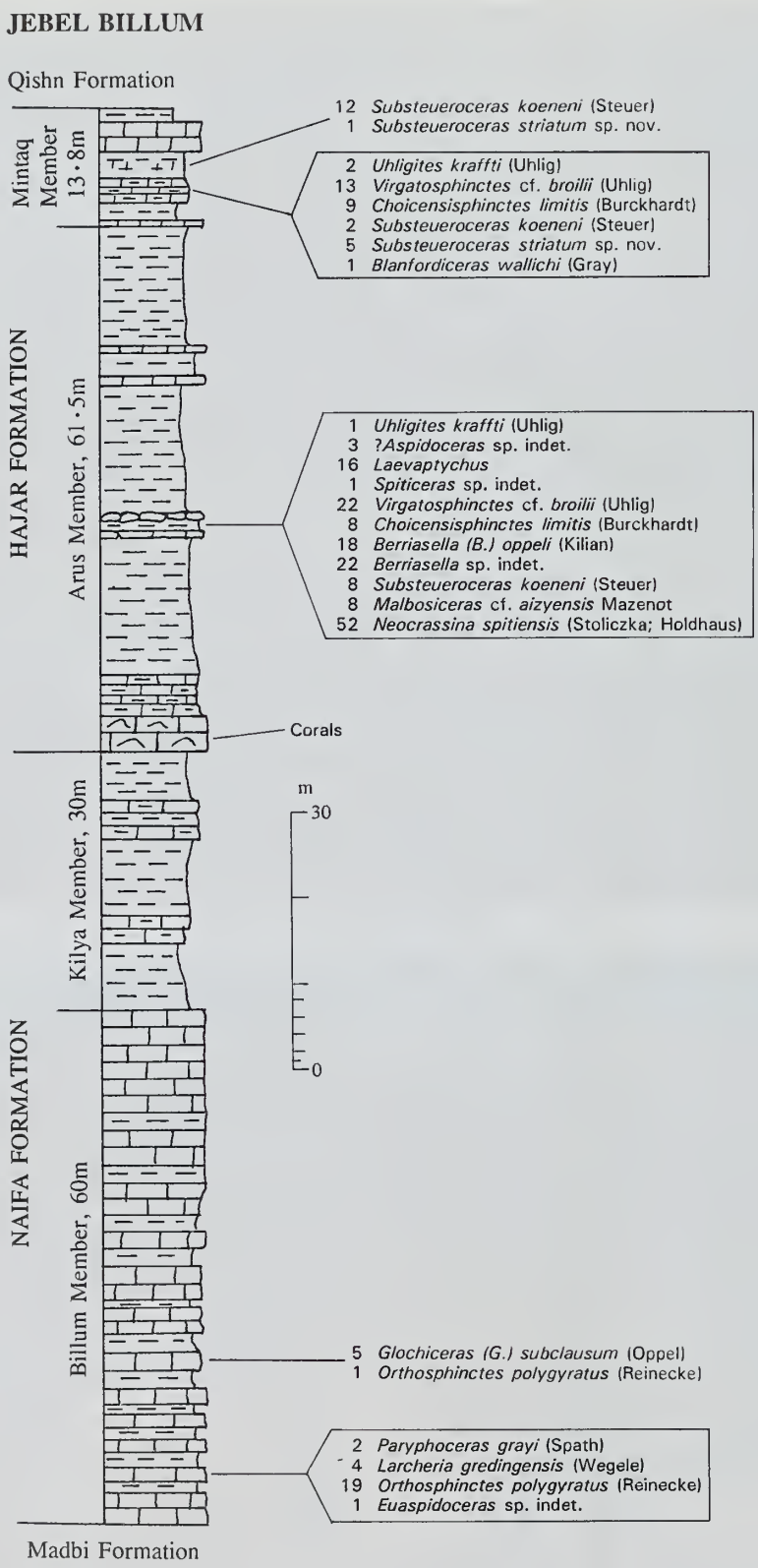


Fig. 12 Vertical section of the Naifa and Hajar Formations in Jebel Billum; the upper half was obtained from the Eastern Jebel Billum locality (EJB on Fig. 7), the lower half from the nearby Perisphinctid Cliff (PC on Fig. 7); the 5 *Glochiceras* and 1 *Orthosphinctes* 18–20 m above the base of the Billum Member were collected in the western entrance road cutting to Jebel Billum.

ferruginous surfaces ('Iron Pans') at central Jebel Billum. This middle part is conveniently divided off as the Middle Shuqra, leaving the more marly limestones of the Upper and Lower Shuqra above and below. The ripple-marks and the 'Iron Pans' marking the top surface were formed during a period of emergence above sea-level. The Middle Shuqra, as so defined, is about 15 m thick at both Al Ma'abir and central Jebel Billum.

BIOSTRATIGRAPHY. The discovery of three specimens of the ammonite *Erymnoceras (Pachyerymnoceras) jarryi* (Douvillé) is important for dating the Shuqra Formation. Two were found 17 m below the top of the Upper Shuqra in the sections at central Jebel Billum and south-east of Al Ma'abir, and the third was in the top part of the Middle Shuqra at the latter locality (Fig. 6). They date the middle and upper parts of the Shuqra as Middle Callovian or low Upper Callovian. No other ammonites have been recorded from the Shuqra. Also of interest is a 0.5 m thick bed of limestone 23 m below the top of the formation in central Jebel Billum, which contains many large, solid, well-preserved specimens of the nautiloid *Paracenoceras meridionale* Tintant; *P. calloviense* (Oppel) occurs at a similar horizon at Al Ma'abir. Both are Callovian in age.

Brachiopods are abundant in the Shuqra Formation. In the Lower Shuqra they are dominated by two or three species of *Daghaniryhnchia*, which are characteristic of this horizon. *Bihenithyris* and *Cererithyris* occur in smaller numbers and there are a few *Conarosia* and *Arabicella*. *Somalirhynchia* appears in the Middle Shuqra, where it is the most abundant brachiopod, and is accompanied by smaller numbers of *Bihenithyris* and *Cererithyris*. In the Upper Shuqra, *Somalirhynchia* remains the most abundant brachiopod, now occurring together with substantial numbers of *Conarosia, Arabicella, Arapsopleurum* and *Cererithyris*, and occasional *Arapsothyris* and *Ptyctothyris*. Though generally Callovian in age, these brachiopods are not well-dated independently elsewhere, except that *Somalirhynchia* is not thought to occur below the Middle Callovian, which is the probable date of the Middle Shuqra.

Several specimens of *Acrosalenia wyvillei* Currie, *Hemicidaris gregoryi* Currie and *Metacrosalenia pseudocidaroides* (Currie) were found near the base of the Shuqra Formation at Al Ma'abir, and although they are Bathonian or Callovian in age elsewhere, these echinoids cannot be dated more precisely.

Many bivalves and gastropods are found in the Shuqra Formation, as seen in the long lists in the appendix. They include the genus *Eligmus*, of which *E. aualites* (Stefanini) is especially common in an horizon 0–2 m above the Nautilus Bed in central Jebel Billum (Fig. 6). *Eligmus* ranges up to the top few metres of the Shuqra, but it does not pass up into the Madbi Formation. The stratigraphical range of *Eligmus* is not thought to extend higher than the top of the Callovian, so, together with the presence of *Erymnoceras*, it is good evidence that the top of the Shuqra Formation is near to the Callovian/Oxfordian boundary.

The Madbi Formation

LITHOLOGY AND TYPE SECTION. The name was proposed by Beydoun (1964: 31–36; see also 1968: 68) from its development on Jebel Madbi, where it was described as an essentially argillaceous formation of marls and shales, between the calcareous Shuqra Formation below and calcareous Naifa Formation above. Beydoun recorded a thickness of 252 m on Jebel Madbi. However, he did not recognize that the limestones that come in approximately 100 m above the base are the limestones of the Naifa Formation (Billum Member). So approximately the upper 152 m of his 252 m thickness on Jebel Madbi is the Naifa Formation, closely similar to its development at Naifa Cliff and Wadi Kilya, and the argillaceous beds of the restricted Madbi Formation on Jebel Madbi are about 100 m thick.

The Madbi Formation is well-developed in Jebel Billum, where it is 111.5 m thick, and also east of the road south-east of the Al Ma'abir river crossing, where it is about 70 m thick. It is argillaceous throughout, and though marls are more common than shales, only occasionally are they sufficiently calcareous to form harder beds of rubbly or marly limestone. A few horizons are silty, gypsiferous or bituminous. The formation is highly fossiliferous, with abundant 'shelly' faunas of brachiopods, bivalves and gastropods. There are also many belemnites, but ammonites are rare and generally fragmentary and poorly preserved. A feature of the Madbi Formation at both Jebel Billum and Al Ma'abir is the 'storm beds': the lowest one, 1–2 m thick, forms the bottom bed of the formation in central Jebel Billum, but is cut out by faulting at Al Ma'abir, while there is another one up to 4 m thick and 16 m higher at Al Ma'abir, and a top one 2 m thick and 43 m higher at central Jebel Billum. They are dark brown, ferruginous, rubbly marls, containing immense numbers of poorly sorted brachiopods, bivalves, oysters, gastropods and belemnites, all heaped up in an unsorted mass as if thrown together by storms (?or by earthquake induced slumping).

BIOSTRATIGRAPHY. The Madbi Formation is Lower and Middle Oxfordian in age: the age of the top is delimited by the Bimammatum Zone, Upper Oxfordian, ammonites in the bottom few metres of the overlying Naifa Formation, while the age of the base cannot be older than the Middle or Upper Callovian date given by the ammonites in the upper part of the Shuqra Formation. Age evidence from the ammonites in the Madbi Formation itself consists of a *Peltoceratoides* in the Middle Storm Bed and *Perisphinctes* in the Upper Storm Bed, both at Al Ma'abir, which suggest a Lower and Middle Oxfordian age respectively. The Shuqra/Madbi Formation junction is probably close to the Callovian/Oxfordian boundary.

Very large numbers of brachiopods occur in the Madbi Formation, especially in the Storm Beds, but they are not well-dated independently elsewhere, and being potentially facies dependent, they do not give a better age assessment of the formation. As in the Middle and Upper Shuqra, *Somalirhynchia* is abundant, and there are now representative species of *Conarosia, Avonithyris, Bihenithyris, Cererithyris, Dissoria, Eurysites, Mycerosia* and *Ptyctothyris*. *Microthyridina* appears in considerable numbers in the Upper Storm Bed at about the middle of the formation, and a few *Somalithyris* appear in the upper part of the formation.

Bivalves and gastropods are also abundant in the Madbi Formation. Many genera continue from the Shuqra Formation, except *Eligmus* which is now absent, and are joined by *Indogrammatodon, Neocrassina* and other genera.

The Naifa Formation

LITHOLOGY AND TYPE SECTIONS. After its description in an unpublished Iraq Petroleum Company report by Pike & Wofford in 1939, the first published accounts of the Naifa Formation were by Beydoun (1964: 31–46; 1968: 80). He designated the section at Naifa Cliff on the south (right) bank of the river, 2 km upstream from the road/river crossing at Al Ma'abir as the type locality. The middle two-thirds of the formation are seen here (Figs 3, 9): the top was removed by erosion before deposition of Quaternary rocks, while the base is seen in nearby sections at the Al Ma'abir road/river crossing and at Wadi Kilya.

The Naifa Formation is essentially calcareous: thick, hard limestones in the lower half, are followed by marls and limestones in the upper half. This slight difference in lithology is the basis of its division into two members, the lower Billum Member and the upper Kilya Member, which are newly proposed here.

Fig. 13 Cliff section on the west side of Wadi Arus; the upper part of the Billum Member forms the low cliff at bottom left, while its top bed forms the limestone platform at the base of the main cliff; the disconformity between the Kilya and Arus Members occurs half way up the face of the main cliff (see Fig. 15 for details).

Fig. 14 The near-vertical beds of the middle part of the Mintaq Member exposed in a gulley in the south-western outcrop of the Mintaq Salt Dome; bed 60, in which most ammonites were found, is the vertical limestone immediately to the left of the tree at the right hand edge of the photograph; the section extends upwards to the left, and the prominent limestone near the lower left edge of the photograph is bed 98.

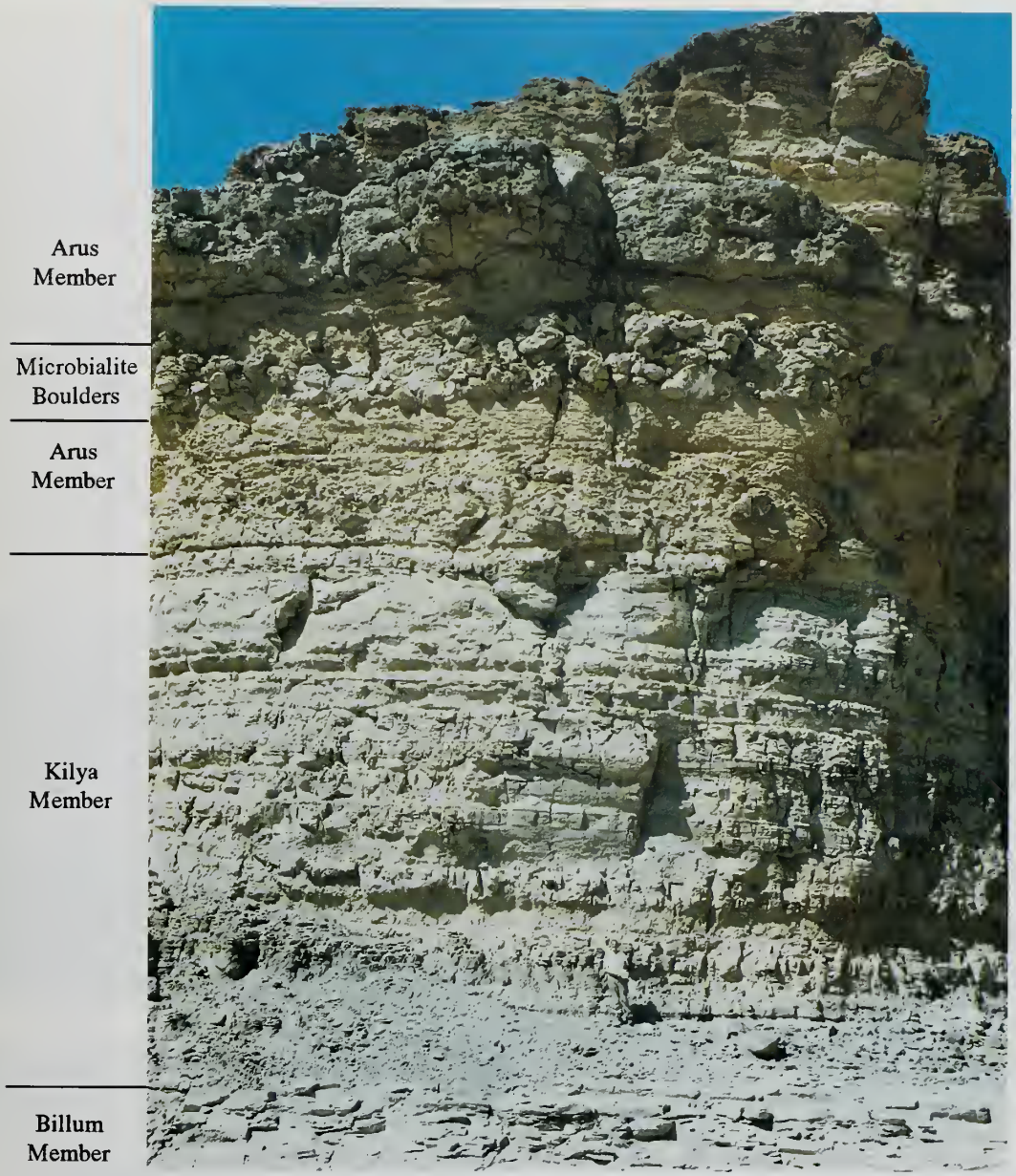


Fig. 15 Detail of the face of the cliff on the west side of Wadi Arus. The figure (1.75 m tall) at the base of the cliff gives a rough scale.

The **Billum Member** is named after its type locality in the lower half of the long cliff in eastern Jebel Billum (Fig. 7, locality PC; Fig. 11), where its basal contact with the Madbi Formation is seen at the bottom of the cliff. It is 60 m thick here, and consists of beds of limestone averaging 0.5 m thick, alternating with thinner beds of marly, flaggy limestone. The Billum Member forms the lowest vertical part of the main cliff in central Jebel Billum (Figs 8, 10), and is cut through in the western road entrance to the Jebel Billum inlier. Approximately the top two-thirds of the Billum Member is exposed in Naifa Cliff. The Billum Member is also seen in a long cliff south of the main section of the Kilya Member on the hillside south of Wadi Kilya, and its basal contact is well exposed here.

The **Kilya Member** is named after its type section on the Qishn-capped hill south of Wadi Kilya, 2 km E by S of Naifa Cliff, which is its most complete development, being 65.4 m thick up to the disconformity at the base of the Qishn Formation (Fig. 5). It contains more marls than the Billum Member, and is subdivided into three parts: marls and thin limestones of the lower and upper parts are separated by a middle part in which thicker limestones are dominant, similar to those of the Billum Member. In Naifa Cliff the lower and middle parts are present but the upper part is missing; ammonite collections were obtained from six horizons, and the lower marly part contains a notable bed of large (0.5 m thick × 1 m diameter) scattered doggers of hard grey limestone (Fig. 3). In Jebel Billum exposures are poor or difficult to reach, but there are good exposures in the cliffs on both sides of Wadi Arus, where the lower marly part

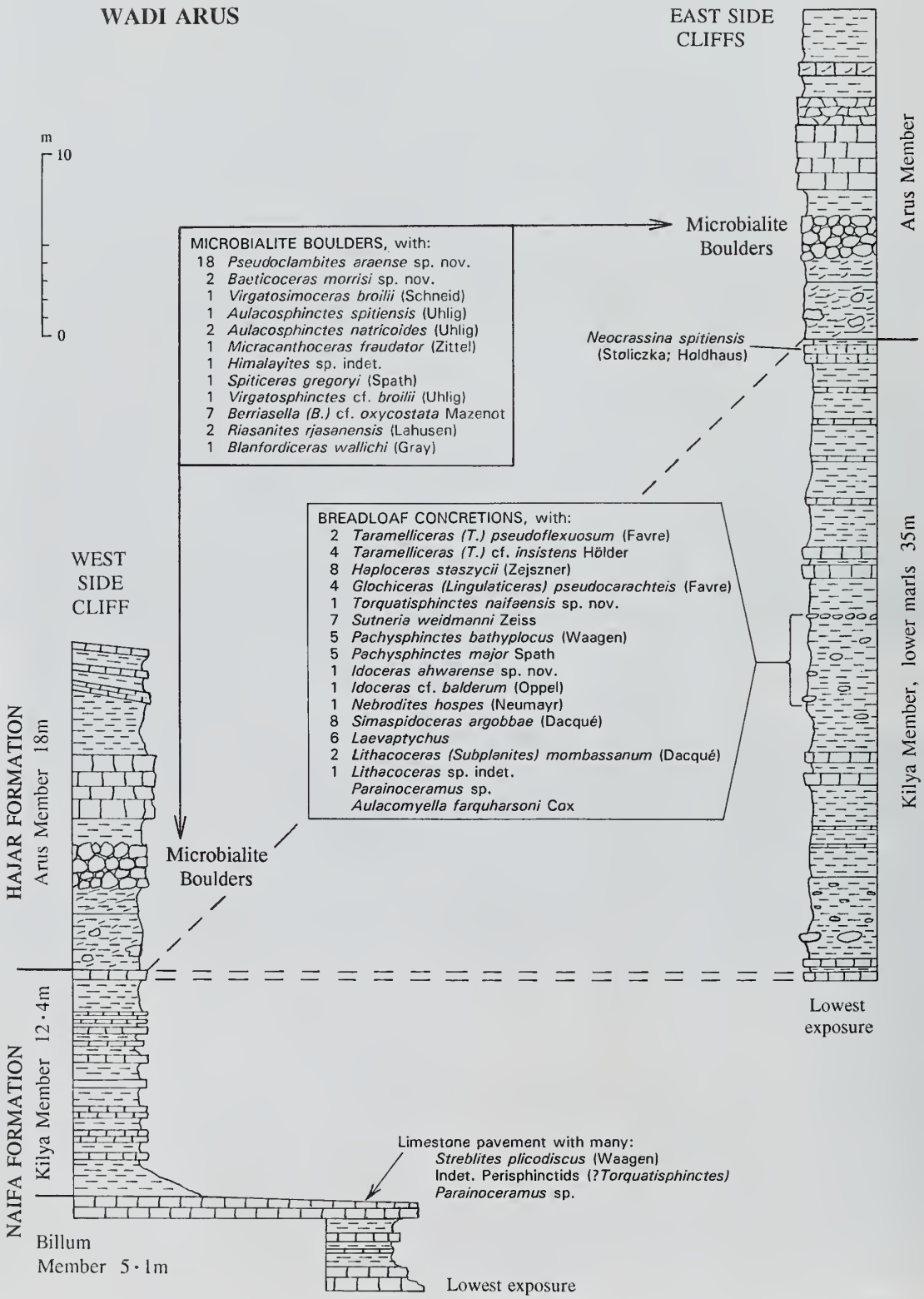


Fig. 16 Vertical sections comparing successions in the Kilya and Arus Members in the opposite east and west cliffs in Wadi Arus.

contains the Breadloaf Concretions (0.25 m × 0.25 m × 0.15 m concretions of hard grey limestone), and also a bed of much larger scattered limestone doggers that may be the same as the bed of similar large doggers in Naifa Cliff.

BIOSTRATIGRAPHY. The age of the Naifa Formation is from the Bimammatum Zone, Upper Oxfordian, to the lower half or two-thirds of the Hybonotum Zone, Lower Tithonian. The contact between the Billum and Kilya Members is at the junction between the Eudoxus and Beckeri Zones or within the lower part of the Beckeri Zone.

1. The Billum Member. The lowest ammonite fauna in the Billum Member occurs in the bottom 5 m in the cliff south of the Wadi Kilya section, and 7–8 m above the base of the member at the base of the Perisphinctid Cliff in eastern Jebel Billum (Figs 5, 12). More than 50 specimens were obtained, belonging to the genera *Ochetoceras, Epimayaites, Larcheria, Paryphoceras, Orthosphinctes* and *Euaspidoceras*, which date the beds as Bimammatum Zone, Upper Oxfordian.

18–20 m above the base of the Billum Member in the road cutting at the western entrance to Jebel Billum *Glochiceras (G.) subclausum* (Oppel) and *Orthosphinctes polygyratus* (Reinecke) were collected (Fig. 12), which indicate a similar Bimammatum Zone age.

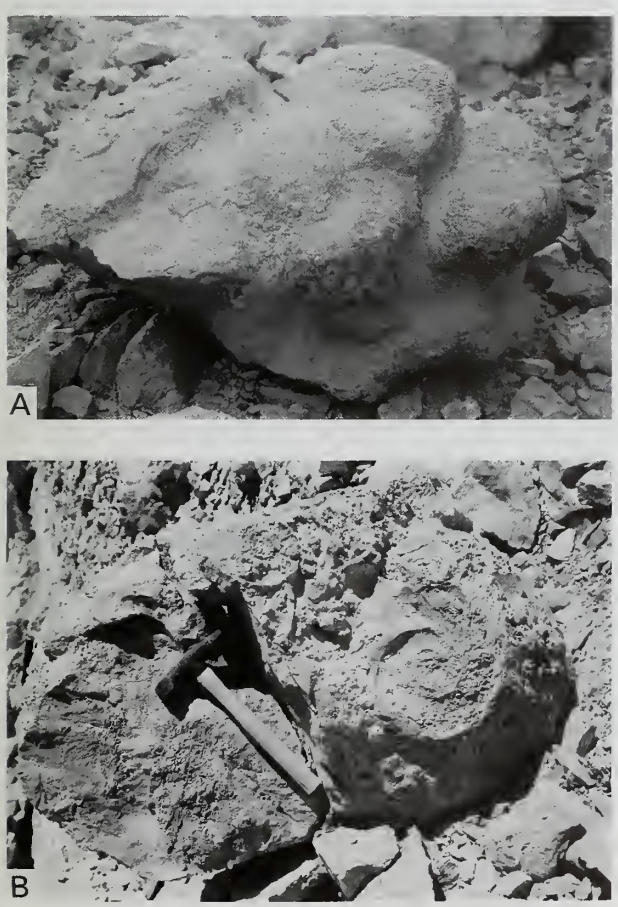


Fig. 17 Microbialite boulders from the bottom of the Arus Formation in Wadi Arus; **A** is a complete boulder with an unbroken upper surface; **B** is a similar boulder broken through the middle showing cross sections of several ammonites; the hammer handle is 34cm long and gives the scale for both photographs.

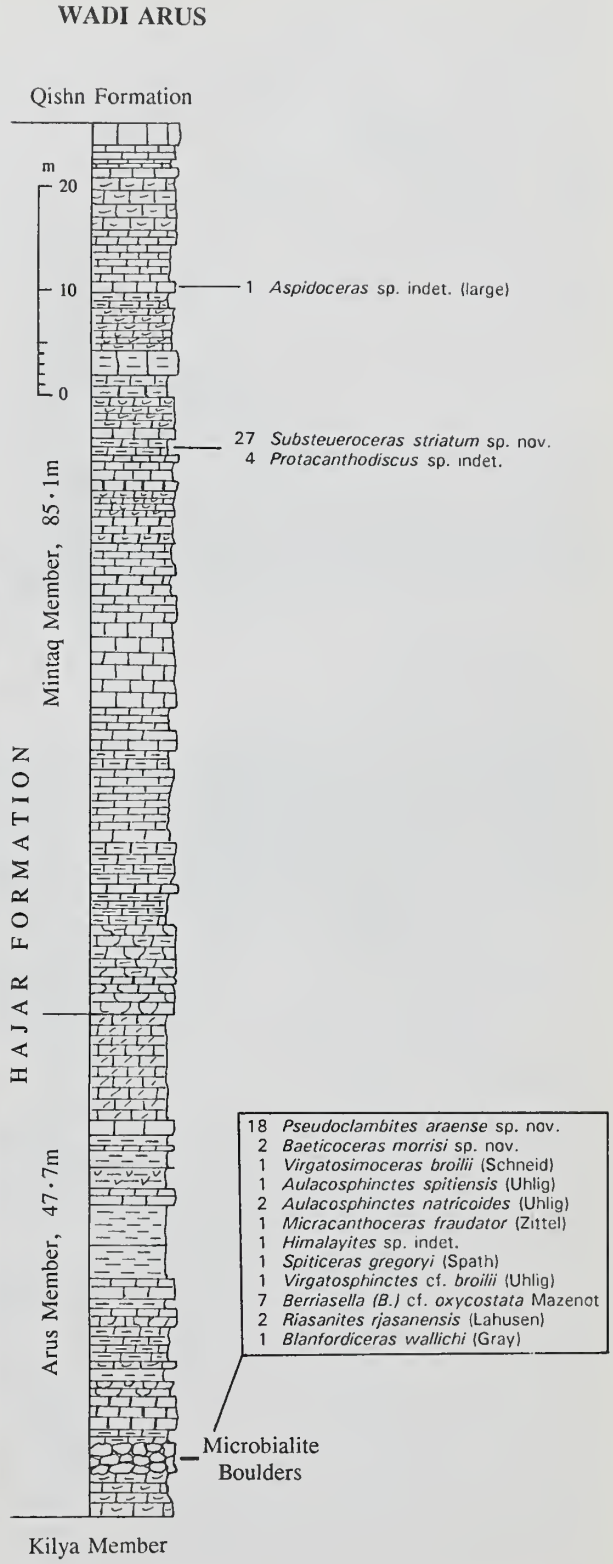
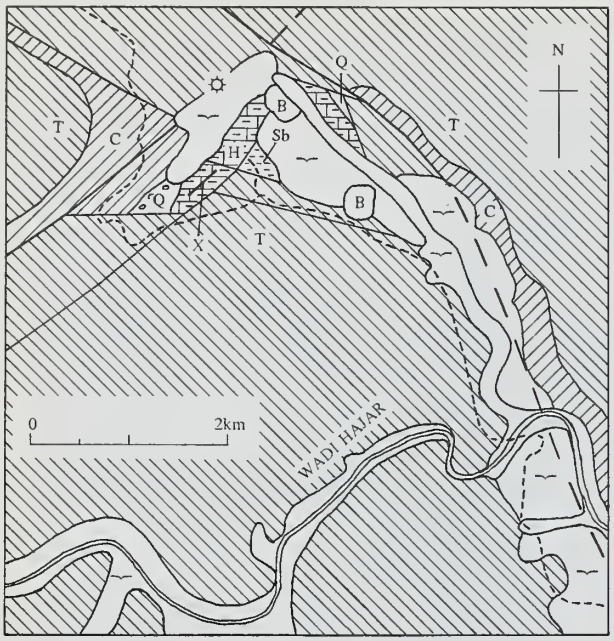


Fig. 18 Vertical section of the full succession of the Hajar Formation in Wadi Arus.



Quaternary
B Basalt, Quaternary
T Tertiary (Palaeocene, Eocene)
C Cretaceous, post-Qishn Formation
Q Qishn Formation, U. Haut.-Aptian
H Hajar Formation, Berriasian
Sb Sabatayn Formation
Unmetalled roads
River in Wadi Hajar
Hot spring

Fig. 19 Geological Map of the Mintaq Salt Dome; **X** is the position of the succession in Figs 14 and 20.

Evidence for the age of the upper part of the Billum Member comes from the large specimen of *Crussoliceras* cf. *wegelei* Enay found in a limestone about 8 m below the top of the member in a roadside cliff east of the Al Ma'abir road/river crossing (Fig. 3), which is of Divisum Zone, Lower Kimmeridgian, date.

The top bed of limestone of the Billum Member forms a pavement below the west side cliff in Wadi Arus and many crushed *Streblites* and indeterminate perisphinctids, some of which are probably *Torquatisphinctes*, can be seen on the surface (Fig. 16). These are of Eudoxus or Beckeri Zone, Upper Kimmeridgian, age.

The abundant brachiopods in the Shuqra and Madbi Formations disappear in the higher formations, except in the lower part of the Billum Member where there are two 0.3 m thick marly limestones, the '*Microthyridina* Beds', 4 m and 9.3 m above the base of the member and well seen at the base of the Perisphinctid Cliff in east Jebel Billum, that contain many large examples of *Microthyridina farquharsoni* Muir-Wood, accompanied by a few *Kallirhynchia* and *Somalirhynchia*. No brachiopods were found higher in the Billum Member.

Bivalves and gastropods are also much less common above the top of the Madbi Formation, though some occur in 'shell beds' and at a few other horizons, such as the '*Microthyridina* Beds' in the bottom 4–9 m of the Billum Member.

2. The Kilya Member. This member is dated as Beckeri Zone, Upper Kimmeridgian, and Hybonotum Zone, Lower Tithonian. The Beckeri Zone is represented by a very rich and mainly well-preserved ammonite fauna found in Wadi Kilya, Naifa Cliff and Wadi Arus. More than 250 ammonites of the following genera were collected: *Taramelliceras, Haploceras, Glochiceras, Torquatisphinctes, Sutneria, Pachysphinctes, Idoceras, Nebrodites, Aspidoceras, Orthaspidoceras, Simaspidoceras* and *Lithacoceras*, and more than 75 *Lamellaptychus* (belonging to *Taramelliceras*) and *Laevaptychus* (from Aspidoceratidae). These ammonites occur at the different horizons in the lower marly and middle limestone parts of the Kilya Member that are shown in detail on Figs 3, 5 and 16, and include well preserved specimens from the Breadloaf Concretions in Wadi Arus. They are well dated as Beckeri Zone, Upper Kimmeridgian.

The upper marly part of the Kilya Member occurs only at Wadi Kilya (Fig. 5), from where 72 ammonites were obtained, many of them well-preserved, belonging to the genera *Taramelliceras, Katroliceras, Subdichotomoceras, Pachysphinctes, Aspidoceras, Orthaspidoceras, Simaspidoceras, Hybonoticeras* and *Lithacoceras*. There are many species in common with the ammonites in the Beckeri Zone below, but the presence of *Katroliceras, Hybonoticeras* cf. *hybonotum* and *H. ornatum* indicate the Hybonotum Zone, Lower Tithonian. This is the date of the highest fauna in the Kilya Member, and the disconformity between it and the Arus Member consists of the remainder of the Hybonotum Zone (if any) and the next four ammonite zones up to the top of the Lower Tithonian.

Brachiopods are rare in the Kilya Member, with only a few terebratulids (*Ptyctothyris* and ?*Cererithyris*) found in the middle limestones and one *Acanthothiris* in the lower marls. An 'Astarte Bed' with many *Neocrassina* occurs 0.3 m below the top of the lower marly part of the Kilya Member in the east cliff in Wadi Arus.

Hajar Formation

LITHOLOGY AND TYPE SECTIONS. The Hajar Formation is a new name proposed here for the calcareous formation that is separated from the underlying Naifa Formation by an unconformity. It is named after Wadi Hajar, and the type section is in the cliffs on both sides of Wadi Arus. It is essentially calcareous, and is divided into two members, newly proposed here: a lower, thinner Arus Member, consisting of marls, limestones, and concretions, and an upper, much thicker Mintaq Member of more massive limestones. Both members are well-developed and thick in Wadi Arus, but the Mintaq Salt Dome and Jebel Madbi are important sections for the fullest development of the Mintaq Member.

The **Arus Member** is named after its type locality in a prominent cliff on the west side of Wadi Arus, where it has a clear contact with the Kilya Member of the Naifa Formation, which it follows after an unconformity that misses out the whole of the Lower Tithonian except for part of its lowest zone (Figs 13, 15, 16). It consists of marls with gypsum and scattered microbialite boulders, then a thick bed of large microbialite boulders, followed by more marls and limestones. The top is better seen in the opposite east cliff where the complete thickness is 47.7 m.

The **Mintaq Member** is named after the development at its type locality in the south-west outcrop of the Mintaq Salt Dome, where there is a good basal contact with the evaporites of the Sabatayn Formation. It consists of 215.7 m of limestones, that are thick and heavy for the lowest 77 m, then there are subsidiary marls and marly

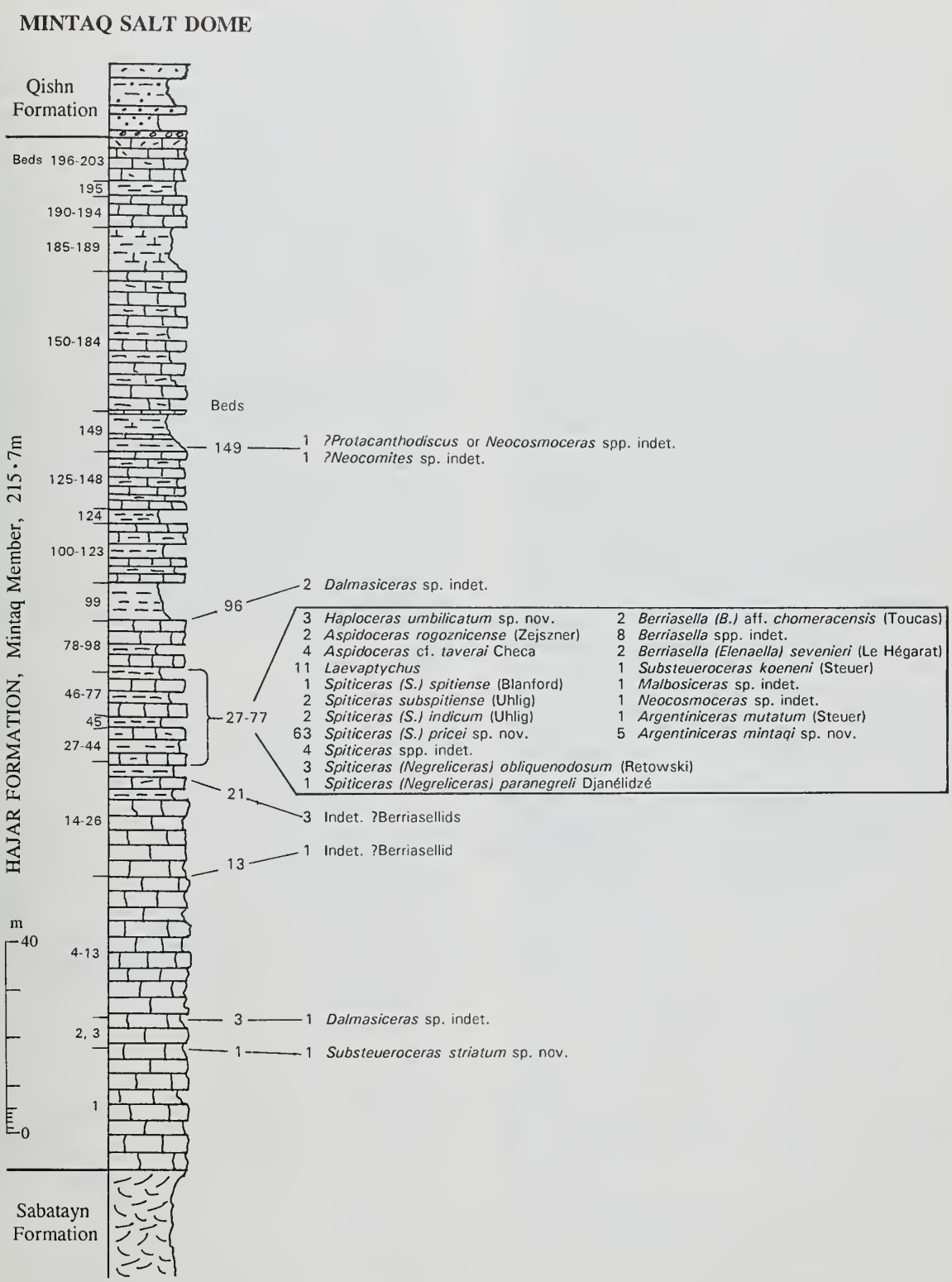


Fig. 20 Vertical section of the Mintaq Member in the south-western outcrop in the Mintaq Salt Dome.

limestones in the remaining 139 m up to a good contact with the overlying Qishn Formation (Figs 14, 19, 20). Another important section of the Mintaq Member is in the east cliff in Wadi Arus (Fig. 18), where it follows the Arus Member conformably, and consists of 85 m of thick limestones, with subsidiary marls and marly limestones, the upper parts of which are well seen in the road gorge leading south-eastwards up out of the wadi. It cannot be proved that the base of the Mintaq Member at Mintaq correlates exactly with the conformable contact between the Arus and Mintaq Members in the east cliff of Wadi Arus, though the gypsum deposits in the Arus Member at Wadi Arus suggests a general correlation with the Sabatayn Formation at Mintaq (see Fig. 2). An even thicker development occurs on Jebel Madbi, where Beydoun recorded 434 m of beds that seem to belong to the Hajar Formation as here defined, and most of that thickness is the Mintaq Member.

BIOSTRATIGRAPHY. The age of the Hajar Formation is from the base of the Upper Tithonian up to about the middle of the Berriasian, the latter date having been proved at Mintaq and Jebel Madbi. The contact between the Arus and Mintaq Members is within the Durangites Zone, probably in the low to middle part of that zone.

1. The Arus Member. The base is well dated in Wadi Arus, where 38 ammonites were obtained from the microbialite boulders (Figs 16, 17) belonging to the genera *Pseudoclambites, Baeticoceras, Virgatosimoceras, Aulacosphinctes, Micracanthoceras, Himalayites, Spiticeras, Virgatosphinctes, Berriasella, Riasanites* and *Blanfordiceras*. All these genera are confined to the Upper Tithonian or younger, except *Virgatosphinctes* and *Virgatosimoceras* which also occur in the Lower Tithonian. The date of the microbialite boulders is Microcanthum Zone, Upper Tithonian. *Baeticoceras morrisi* sp. nov. is most probably of basal Microcanthum Zone age, deduced from its morphological features and probable relationships with other species of the genus, but some of the other ammonites are better placed higher in the Microcanthum Zone, suggesting that the microbialite boulders might be a condensed horizon. Noteworthy are two examples of the mainly Boreal species *Riasanites rjasanensis* (Lahusen), and the rare ammonite *Pseudoclambites* which is poorly known elsewhere.

An ammonite fauna that is almost completely different from that in the microbialite boulders in Wadi Arus occurs in the lower to middle part of the Arus Member in eastern Jebel Billum (Fig. 12). 91 ammonites were obtained belonging to the genera *Uhligites, ?Aspidoceras, Spiticeras, Virgatosphinctes, Choicensisphinctes, Berriasella, Substeueroceras* and *Malbosiceras*, as well as 16 *Laevaptychus* (aptychi from Aspidoceratidae). The commonest genus is *Berriasella* (with 40 specimens collected), and the age is Durangites Zone, Upper Tithonian, from the presence of *Malbosiceras* and *Substeueroceras*. This is slightly younger than the date of the microbialite boulders in Wadi Arus.

The only brachiopods seen in the Arus Member were two specimens of an unidentified smooth terebratulid in the microbialite boulders in Wadi Arus. Molluscs occur in the shell just below the middle of the Arus Member in east Jebel Billum, especially the astartid *Neocrassina*, and there are a few bivalves and gastropods in the Coral Bed at the base of the Arus Member in the same section.

2. The Mintaq Member. The base is well exposed in eastern Jebel Billum where 45 ammonites were collected in the basal 6 m (Fig. 12), belonging to the genera *Uhligites, Virgatosphinctes, Choicensisphinctes, Substeueroceras* and *Blanfordiceras*. Although these are only slightly different from the ammonites 40 m below in the Arus Member in the same section, *Substeueroceras* makes up a higher proportion of the total, and with *Blanfordiceras*, suggests a slightly higher horizon in the Durangites Zone for the base of the Mintaq Member.

Few ammonites were found in the Mintaq Member in Wadi Arus, but a limestone in the upper half contains many crushed *Substeueroceras striatus* sp. nov. and *Protacanthodiscus*. sp. indet., and a large *Aspidoceras* sp. indet. was photographed nearer the top of the member. These are either Durangites Zone, Upper Tithonian, or Euxinus Zone, lower Berriasian, in age. This might also be the date of the lowest ammonites (*Substeueroceras* and *Dalmasiceras*) in beds 1 and 3 in the Mintaq Salt Dome (Fig. 20).

The main evidence for the Berriasian age of much of the Mintaq Member comes from rich ammonite fauna in the middle part of the member at Mintaq (Fig. 20), where 108 specimens were collected of the genera *Haploceras, Aspidoceras, Spiticeras, Berriasella, Substeueroceras, Malbosiceras, Neocosmoceras, Dalmasiceras,* and *Argentiniceras*, and 11 *Laevaptychus*.

The presence of *Argentiniceras*, a rich and varied fauna of *Spiticeras* including typical well-developed species, and two species of *Berriasella, B. (B.) chomeraciensis* (Toucas) and *B. (Elenaella) sevenieri* (Le Hégarat), give an Occitanica Zone age, close to or just below the middle of the Berriasian.

Finally, two *Tirnovella occitanica* (Pictet) collected by Dr John Smewing from near the top of the Mintaq Member on the summit of Jebel Madbi, are also of Occitanica Zone, mid-Berriasian, age, though they might be slightly higher in that zone than the Mintaq ammonites. The age of the top of the Hajar Formation on Jebel Madbi is not known, but is likely to be in the upper part of the Berriasian.

No brachiopods or identifiable bivalves and gastropods were found in the Mintaq Member, except for a few poorly preserved bivalves in the base of the member in east Jebel Billum.

Qishn Formation

LITHOLOGY AND TYPE SECTIONS. The type locality of the Qishn Formation is at Ras Sharwayn, near Qishn, 290 km ENE of Mukalla, where it is 411 m thick and consists of brecciated limestone at the base, followed by limestones and marls, then hard crystalline limestones containing *Orbitolina* in the upper half (Beydoun, 1968: 91). A similar section in Wadi Masila, 70 km to the west, reaches a total thickness of 498 m. In the Wadi Hajar and Mukalla areas the formation is much thinner, being only 54.5 m thick in Beydoun's reference section at Jabal al Rays, near Mukalla, where there is a conglomerate at the base, then marls and sandstones, and the *Orbitolina* Limestone is 17.5 m thick at the top. Two sections measured by us in Wadi Hajar are in east Jebel Billum and at the Mintaq Salt Dome. In east Jebel Billum the 31.9 m thick Qishn Formation is at the top of the cliff immediately above the section shown in Fig. 12; it consists of 5 m of shelly, cross-bedded, calcified sandstones and silts, then 17.3 m of marls, mudstones and marly limestones, up to the 9.6 m thick hard *Orbitolina* Limestone at the top. In the whole of the Jebel Billum inlier, the red-brown basal beds of the Qishn Formation make an easily recognizable colour change near the top of the cliffs of the grey Naifa and Hajar Formations. In the Mintaq Salt Dome the Qishn Formation is 77.8 m thick: 0.8 m of conglomeratic sandstone at the base, passes into sandstones, silts and mudstones 69.4 m thick, including two oyster beds, up to the massive *Orbitolina* Limestone 7.6 m thick at the top.

BIOSTRATIGRAPHY. The main reason for including the Qishn Formation in this description is to record the discovery of a single example of the ammonite *Crioceratites (C.) villiersianum* (d'Orbigny) in the east Jebel Billum section (Howarth, 1998: 98, pl. 23, fig. 2). Although found lying loose at the top of the Hajar

Formation, it had certainly fallen from the shelly sandstone, 5 m thick at the base of the Qishn Formation immediately above. It is Upper Hauterivian in age, and is the first date obtained for this basal part of the formation. The *Orbitolina* Limestone is generally recognized to be Upper Barremian in age from the foraminifera (*Palorbitolina lenticularis* (Blumenbach) and *Choffatella decipiens* Schlumberger) that it contains (Beydoun, 1968: 92). Three ammonites were recorded by Beydoun, 1968: 93) from the upper half of the 498 m thick Qishn Formation in the Wadi Masila section referred to above: *Cheloniceras (C.) cornuelianus* (d'Orbigny) (BMNH C.86982; figured Howarth, 1998, pl. 21, fig. 3), *Cheloniceras (C.)* sp. indet. (BMNH C.86983, recorded as *C. martini* (d'Orbigny) by Beydoun; figured Howarth, 1998, pl. 21, fig. 4) and ?*Cheloniceras* (BMNH C.71676, recorded as *Douvilleiceras* sp.), which all indicate an Upper Aptian age at that level. However, the specimen of *Crioceratites* from the base of the formation is a whole stage earlier than previous dates obtained for the Qishn Formation.

CORRELATION WITH EAST AFRICA

The Jurassic and Cretaceous rocks of Yemen and Somalia were deposited before the opening of the Gulf of Aden, which commenced with rifting in the Oligocene followed by sea-floor spreading from the late Miocene onwards (Abbate *et al*, 1988: 440–442). The geology of the southern coastal areas of Yemen and northern Somalia was described and compared by Beydoun (1970), from whose work the diagram of Fig. 21 was drawn, using the best-fit of the pre-rifted structures. The best described Jurassic sequence in northern Somalia is near Bihendula, which can be seen from Fig. 21 to have been only 225 km south-west of the Wadi Hajar area in the Jurassic, compared with the present-day post-rifting separation of 580 km. The sequence near Bihendula was described by MacFadyen (1933) and the ammonites in the succession were described by Spath (1935). A summary of the age assessments was given by Arkell (1956: 308–312), and a more recent update of the lithostratigraphy, including a vertical section of the succession at Bihendula, can be found in Bosellini (1989: 412 &c, fig. 33). As expected, there is much similarity between the Jurassic sequences of Wadi Hajar and Bihendula, and the following comparison can be made:

WADI HAJAR	BIHENDULA
Hajar Formation	?Gawan Limestone
Naifa Formation, Kilya Member	Daghani Shales
Naifa Formation, Billum Member	Wanderer Limestone
Madbi Formation	Gahodleh Shales
Shuqra Formation	Bihen Limestone
Kohlan Formation	Adigrat Sandstone

The initial correlation is based on similar or near-identical lithology in the two areas, suggesting that they were probably within the same basin of deposition. However, there are differences in relative thicknesses (eg. the Daghani Shales are much thicker (370 m) than the Kilya Member (65 m) or the combined Kilya and Arus Members (113 m)), but the ammonites and other faunas described from the two sequences lend considerable support to this correlation. The most useful ammonites for age dating in Somalia were collected from a section that extended through all the formations, at Daghani, 6 km east of Bihendula, which was described by MacFadyen (1933: 28) and Spath (1935: 206–208). The correlation given above is not the same as the correlation suggested by Beydoun (1964: 45, table 4), which was not based on a comparison of the ammonite faunas in the two areas.

The Kohlan and the Adigrat Sandstone are similar arenaceous

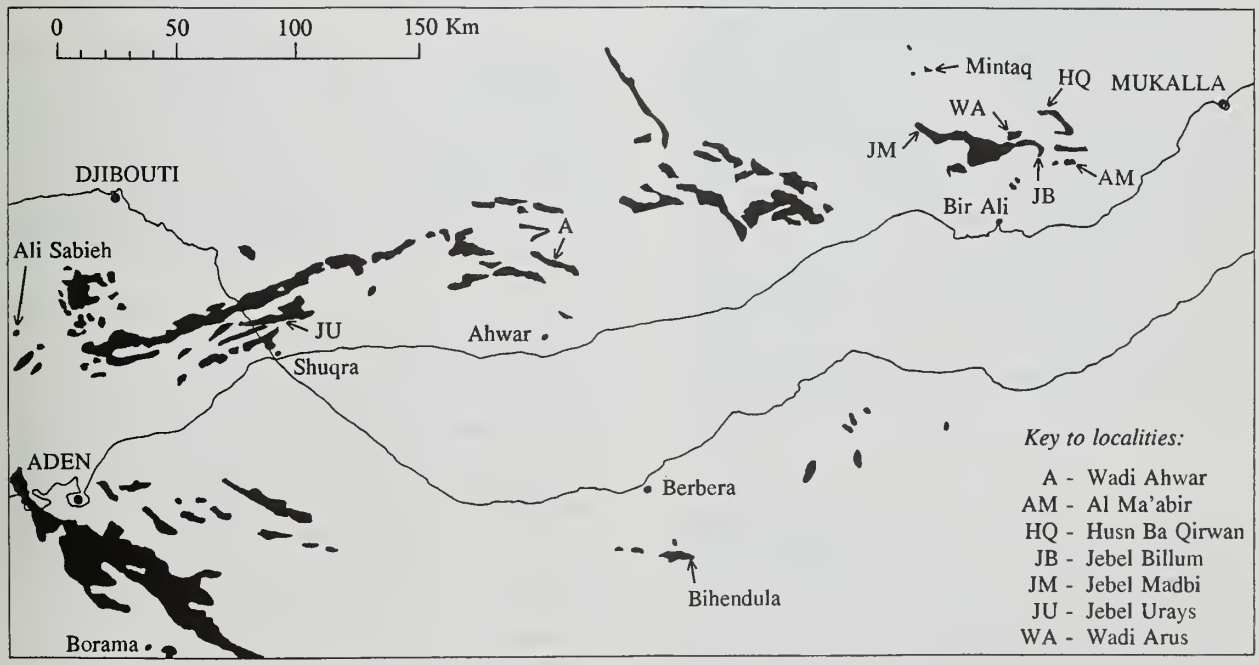


Fig. 21 The Jurassic outcrops in Wadi Hajar and northern Somalia, showing their relative position before the formation of the Gulf of Aden in the Miocene. Outcrops of Jurassic are shown in solid black. Redrawn from Beydoun, 1970, figs 2–4; the fit between Yemen and Somalia is at the 500 fathom (approx. 1000 m) isobath, which leads to a minimum (and very small) amount of superposition of Basement, Mesozoic and recent volcanic rocks in the overlap triangle between Aden and Djibouti.

formations, both mainly non-marine and difficult to date, though both probably range from late Triassic (Adigrat Sandstone) or Lower Jurassic (Kohlan Formation) to Middle Jurassic (probably Bathonian).

The Shuqra Formation and Bihen Limestone contain rich, near-identical faunas of brachiopods, molluscs and some echinoids, but rare mid-Callovian ammonites occur in the Shuqra Formation, and a loose Upper Bathonian *Paracenoceras* and a loose Upper Callovian or Lower Oxfordian *Pachyceras* are probably both from the Bihen Limestone.

The Madbi Formation and Gahodleh Shales are both argillaceous formations of Oxfordian age, though excluding the highest part of that stage, as deduced from the poor ammonites in the Madbi and the ages of the adjacent formations in both areas. Both formations contain many of the same brachiopods and molluscs.

The Naifa Formation, Billum Member, and the Wanderer Limestone contain several similar or identical ammonites. There are many difficult-to-determine crushed perisphinctids of Upper Oxfordian or lowest Kimmeridgian appearance in the Wanderer Limestone, but the presence of *Orthosphinctes polygyratus* (Reinecke) and a ?*Larcheria* dates at least part of it to the Bimammatum Zone, Upper Oxfordian, as in the lowest part of the Billum Member. Other ammonites in the Wanderer Limestone might be higher in the Kimmeridgian, but there is nothing that is definitely determinable as being of the same age as the Eudoxus or Beckeri Zone ammonites at the top of the Billum Member.

The Kilya Member and the Daghani Shales both contain ammonites from the Beckeri Zone at the top of the Kimmeridgian. Others in the Daghani Shales could be lower in the Kimmeridgian (*Torquatisphinctes, Idoceras, Sutneria* and some aspidoceratids), while it cannot be proved that the Daghani Shales extends up into the Lower Tithonian, like the Kilya Member. Nevertheless, the two formations are similar in age, and better preserved ammonites would be needed from Somalia to make a more exact comparison.

The Hajar Formation and the Gawan Limestone represent a return to more calcareous conditions of deposition in both areas. The two formations might be similar in age, and Spath's (1935: 206) determinations of the poorly-preserved ammonites in the Gawan Limestone as *Aulacosphinctes, Anavirgatites, Pseudovirgatites, Sublithacoceras* and *Simoceras* certainly indicate a Tithonian age, though they could be Lower Tithonian, so it is not possible to show an exact equivalence with the Hajar Formation. The disconformity that excludes most of the Lower Tithonian in Wadi Hajar in Yemen might be absent, or it might be present at a lower biostratigraphical horizon, in Somalia, and the absence of any ammonites in the top 142 m of the Gawan Limestone means that neither the Upper Tithonian nor the Berriasian can be proved to be present in that formation. The correlation of the Hajar Formation and the Gawan Limestone is still tentative, and further progress also requires better ammonites from Somalia.

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APPENDIX

Macrofossils collected in Wadi Hajar. Ammonites identified by M.K. Howarth, brachiopods by Dr E.F. Owen, echinoderms by Dr Andrew Smith, and bivalves and gastropods by N.J. Morris. The bed numbers listed for the Mintaq section refer to those in the vertical section of Fig. 20. Numbers in square brackets are the number of specimens collected.

Naifa Cliff (N14°16'38" E48°32'52")

Naifa Formation, Kilya Member:

Marly limestone, 41.5 m above base. Ammonites: *Pachysphinctes* spp. indet. [15], *Aspidoceras longispinum* (J. de C.Sowerby) [2].

Limestone and marl, 0.4 m thick, 22.0–22.4 m above base; the main ammonite bed in Naifa Cliff. Ammonites: *Taramelliceras* sp. indet. [2], *Lamellaptychus* [6], *Pachysphinctes bathyplocus* (Waagen) [21], *Pachysphinctes major* Spath [23], *Pachysphinctes mahokondobeyrichi* (Dietrich) [5], *Idoceras* cf. *hararinum* Venzo [1], *Aspidoceras longispinum* (J. de C. Sowerby) [3], *Aspidoceras* or *Orthaspidoceras* sp. indet. [1], *Simaspidoceras argobbae* (Dacqué) [1], *Laevaptychus* [7], *Lithacoceras (L.)* cf. *ulmense* (Oppel) [1], *Lithacoceras (Subplanites) mombassanum* (Dacqué) [4]. **Bivalves:** *Palaeonucula* sp. [14].

Limestone 19 m above base. Ammonites: *Orthaspidoceras gortanii* (Venzo) [5].

Row of limestone nodules in marl band, 16 m above base. Ammonites: *Pachysphinctes bathyplocus* (Waagen) [1]; *Simaspidoceras argobbae* (Dacqué) [4]; *Simaspidoceras irregulare* (Dacqué) [1].

Calcareous mudstone, 13.4 m above base. Ammonites: *Torquatisphinctes naifaensis* sp. nov. [7].

Marls, 12 m above base. Bivalves: *Parainoceramus* sp. [1], *Liostrea* sp. [1].

Limestone, 1.4 m above base. Perisphinctid indet. [1].

Naifa Formation, Billum Member:

Shell Bed, 12 m below top. Bivalves: ?*Palaeonucula* sp. [many].

Al Ma'abir road/river crossing, west side (N14°16'05" E48°33'33")

Naifa Formation, Billum Member:

Near base (gently dipping, against cliff). Ammonite: *Ochetoceras* sp. indet. [1]. **Brachiopods:** *Microthyridina farquharsoni* Muir-Wood [13]. **Bivalves:** *Indogrammatodon egertonianus* (Stoliczka) [1], *Modiolus* sp. [2], ?*Limaria* sp. [1], *Nannogyra fourtaui* (Stefanini) [13], *Actinostreon solitaria kindopeensis* (Cox) [8], *Trigonia* sp. [1].

Madbi Formation:

Near top. Bivalves: *Indogrammatodon egertonianus* (Stoliczka) [8], ?*Modiolus* sp., *Nannogyra fourtaui* (Stefanini) [7], *Actinostreon* aff. *solitaria* (J. Sowerby) [2], *Trigonia* sp. [1], ?*Neocrassina* sp. [1], *Colpomya* sp. [1].

Al Ma'abir, new road cutting, 0.5 km east of the road/river crossing

Naifa Formation, Billum Member:

Upper part. Ammonite: *Crussoliceras* cf. *wegelei* Enay [1].

Middle part. Bivalve: *Indogrammatodon egertonianus* (Stoliczka) [1].

Al Ma'abir, from road 0.6 km south-east of river crossing to 1 km eastwards (N14°15'59" E48°34'01")

Madbi Formation:

1 m below top. Bivalves: *Indogrammatodon egertonianus* (Stoliczka) [1], *Limaria* cf. *mandawaensis* Cox [1], *Nannogyra fourteaui* (Stefanini) [2].

Upper Storm Bed, 30 m below top of formation. Ammonites: *Perisphinctes* s.s. sp. indet. [8]. **Brachiopods:** ?*Conarosia* sp. [25], *Microthyridina farquharsoni* Muir-Wood [83]. **Bivalves:** *Indogrammatodon egertonianus* (Stoliczka) [1], *Modiolus* cf. *bipartitus* J. Sowerby [14], *Camptonectes* sp. [3], *'Chlamys'* sp. [1+], *Eopecten* cf. *aubreyi* (Douvillé) [1], *Ctenostreon* sp. [1], *Limaria* cf. *mandawaensis* Cox [7], *Deltoideum delta* (Smith) [20], *Nannogyra fourtaui* (Stefanini) [29], *Actinostreon* aff. *solitaria* (J. Sowerby) [27], *Arctostrea eruca* (Lamarck) [3], *Trigonia* sp. [3], *'Lucina'* sp. [1], ?*Myoconcha* sp. [3], *Neocrassina* aff. *unilateralis* (J. de C. Sowerby) [22], *Pseudotrapezium* sp. of Cox [1], ?*Pleuromya* sp. [1]. **Gastropods:** *Bathrotomaria* sp. [1], *Rhabdoconcha* sp. [5].

36–38 m below top. Brachiopods: *Somalirhynchia africana* Weir [1], *S. arabica* Cooper [38], *S. somalica* (Dacqué) [36], *Avonothyris* sp. [13], *Cererithyris* cf. *wyvillei* (Weir) [8], *Dissoria obscura* Cooper [4], *Eurysites transversus* Cooper [19], ?*Gyrosina* ?sp. nov. [1], *Ornithella* sp. [4], *Ptyctothyris daghaniensis* Muir-Wood [12], *'Terebratula' aulites* Stefanini [4]. **Bivalves:** *Indogrammatodon egertonianus* (Stoliczka) [1], *Arcomytilus* ?sp. nov. [1], *Nannogyra fourtaui* (Stefanini) [2], *Actinostreon* aff. *solitaria* (J. Sowerby) [2], *Trigonia* sp. [1].

Middle Storm Bed, 49 m below top. Ammonites: *Perisphinctes* sp. indet. [2], *Peltoceratoides* sp. indet. [1]. **Brachiopods:** *Daghanirhynchia* sp. [1], *Septirhynchia* sp. (juv.) [1], *Somalirhynchia somalica* (Dacqué) [7], *Bihenithyris deformata* Cooper [5], *Ptyctothyris daghaniensis* Muir-Wood [4]. **Bivalves:** *Palaeonucula* sp. [3], *Indogrammatodon egertonianus* (Stoliczka) [14], *Camptonectes* sp. [1], *Nannogyra fourtaui* (Stefanini) [8], *Actinostreon* aff. *solitaria* (J. Sowerby) [4], *Trigonia* sp. [1], *Neocrassina* aff. *unilateralis* (J. de C. Sowerby) [6]. **Gastropods:** *Proconulus arabiensis* (Newton) [28].

Shuqra Formation:

Upper Shuqra:

Upper part. Bivalves: *'Brachidontes' somalicus* Cox [2], *Modiolus* cf. *bipartitus* J. Sowerby [1], *Eligmus humei* (Stefanini) [2], *E. aualites* (Stefanini) [1], *'Gryphaea' balli* (Stefanini), ?*Myoconcha* sp. [1], *Procyprina hunti* (Cox) [1], *Pseudotrapezium* sp. of Cox [1], *Ceratomyopsis somaliensis* (Weir) [1], *Tellurimya* ?sp. nov. [1], *Bucardiomya somaliensis* (Cox) [1]. **Gastropod:** ?*Rhabdoconcha* sp. [1].

17 m below top, rubbly marls and nodular limestones. Ammonite: *Erymnoceras (Pacherymnoceras) jarryi* (Douvillé) [1].

Loose. Brachiopods: *Somalirhynchia africana* Weir [19], *Somalirhynchia* sp. [32], *Avonothyris* sp. [11], *Cererithyris* sp. [18], *Pleuraloma labiatum* Cooper [1]. **Echinoid:** *Holectypus* sp. [1]. **Crinoid:** ?*Millericrinus* sp. [3].

Middle Shuqra:

2–5 m below top. Ammonite: *Erymnoceras (Pachyerymnoceras)* cf. *jarryi* (Douvillé) [1]. **Brachiopods:** *Somalirhynchia* sp. [13], *Conarosia* sp. [3], *Dissoria obscura* Cooper [10], *'Loboidothyris' aethiopoca* Weir [17]. **Crinoid:** ?*Millericrinus* sp. [2]. **Corals:** (not yet determined). **Stromatoporoid:** *Shuqraia* sp. [1]. **Bivalves:** *'Brachidontes' somalicus* Cox [2], *Modiolus* cf. *bipartitus* J. Sowerby [1], *Eligmus humei* (Stefanini) [2], *Eopecten* cf. *aubreyi* (Douvillé) [2], *'Gryphaea' balli* (Stefanini) [5], *Actinostreon solitaria* (J. Sowerby) [1], *'Lucina'* sp. [1], *Procyprina hunti* (Cox) [2], *Ceratomyopsis somaliensis* (Weir) [2], *Ceratomya* cf. *wimmisensis* (Gilliéron) [1]. **Gastropods:** *Rhabdoconcha* sp. [5], *Ampullospira* sp. [3].

Lower part. Bivalves: ?*Antiquicyprina* sp. [15]. **Gastropods:** ?*Nerinella* sp. [39], ?*Ampullospira* sp. [9].

Lower Shuqra:

28.5 m above base. Brachiopods: *Daghanirhynchia* sp. [2].

15.25 m above base. Bivalves: ?*Palaeonucula* sp. [1], *'Gryphaea' balli* (Stefanini) [2].

10.5 m above base. Brachiopods: *Daghanirhynchia* cf. *macfadyeni* Muir-Wood [16], *D. daghaniensis* Muir-Wood [57]. **Echinoids:** *Acrosalenia wyvillei* Currie [2], *Hemicidaris gregoryi* Currie [1], *Metacrosalenia pseudocidaroides* (Currie) [3]. **Bivalves:** ?*Palaeonucula* sp. [2], *'Gryphaea' balli* Stefanini [1], ?*Procyprina hunti* (Cox) [11], *Pseudotrapezium* sp. of Cox [1], ?*Eomiodon* sp. [1]. **Gastropods:** *Ampullospira* sp. [2].

Loose. Brachiopods: *Daghanirhynchia* cf. *macfadyeni* Muir-Wood

[13], *D. daghaniensis* Muir-Wood [30], *Daghanirhynchia* ?sp. nov. [142], *Arabicella arabis* Cooper [7], *Bihenithyris* cf. *barringtoni* Muir-Wood [33], *B. weiri* Muir-Wood [1], *Cererithyris* sp. [13]. **Bivalves:** ?*Palaeonucula* sp. [1], *Modiolus* cf. *imbricatus* J. Sowerby [4], ?*Bakevellea* sp. [2], *Eligmus* cf. *rollandi* (Douvillé) [1], *Camptonectes* sp. [4], *'Gryphaea' balli* Stefanini [3], ?*Actinostreon* sp. [2], *'Lucina'* sp. [2], ?*Sphaera* sp. [3], *Tendagurium* sp. [13], ?*Antiquicyprina* sp. [1], *Procyprina hunti* (Cox) [11], ?*Eocallista krenkeli* Cox [2], *Bucardiomya somaliensis* (Cox), ?*Homomya* cf. *gibbosa* (J. Sowerby) [1]. **Gastropods:** *Ampullospira* sp. [7], ?*Nerinella* sp. [1].

Wadi Kilya, Al Ma'abir (N14°16'15" E48°34'11").

Collections were made on the southern slope of a hill capped by Qishn Formation on the south side of Wadi Kilya, 2 km E by S of Naifa Cliff.

Qishn Formation:

***Orbitolina* Limestone. Echinoids:** *Holectypus* or *Coenholectypus* sp. [1], ?*Stereocidaris* sp. [1].

Loose, from below *Orbitolina* Limestone. Brachiopods: *Zittelina* sp. ?nov. [12], Terebratulidae [fragments]. **Bivalves:** *Neithea atava* (Roemer) [1], *'Exogyra'* cf. *tuberculifera* Koch & Dunker [7], ?*Amphidonte* sp. [9], *Pholadomya valangiensis* Pictet & Campiche [1]. **Gastropods:** *'Natica'* sp. [11], *Harpagodes* sp. [1], ?*Nerinella* sp. [2].

Naifa Formation, Kilya Member:

Upper Marls: 5–7 m below base of Qishn Formation. Ammonites: *Taramelliceras (Metahaploceras) subsidens* (Fontannes) [9], *Katroliceras formosum* Spath [32], *Katroliceras pottingeri* (J. de C. Sowerby) [1], *Katroliceras* sp. indet. [7]. *Subdichotomoceras ?latissimum* (Zwierzycki) [1], *Pachysphinctes bathyplocus* (Waagen) [5], *Pachysphinctes major* Spath [5], *Pachysphinctes* sp. indet. [9], *Aspidoceras longispinum* (J. de C. Sowerby) [3], *Orthaspidoceras avellanum* (Zittel) [2], *Simaspidoceras argobbae* (Dacqué) [1], *Simaspidoceras irregulare* (Dacqué) [1], *Laevaptychus* [1], *Hybonoticeras ornatum* (Spath) [2], *Hybonoticeras* cf. *hybonotum* (Oppel) [1], *Lithacoceras (L.)* cf. *ulmense* (Oppel) [1]. *Lithacoceras (Subplanites) mombassanum* (Dacqué) [1].

Middle limestones:

Top bed. Ammonite: *Pachysphinctes bathyplocus* (Waagen) [1].

3–7 m below top. Ammonites: *Taramelliceras (T.) compsum* (Oppel) [4], *Taramelliceras* sp. indet. [1], *Pachysphinctes bathyplocus* (Waagen) [4], *Pachysphinctes major* Spath [10], *Nebrodites hospes* (Neumayr) (photos only) [3+], *Aspidoceras longispinum* (J. de C. Sowerby) [3], *Aspidoceras apenninicum* (Zittel) [9], *Aspidoceras* sp. indet. [1], *Laevaptychus* [2], *Lithacoceras (Subplanites) mombassanum* (Dacqué) [6]. **Nautiloid:** *Paracenoceras* sp. indet. **Brachiopods:** ?*Cererithyris* sp., *Ptyctothyris* sp. **Bivalves:** *Parainoceramus* sp. [1], *Liostrea* cf. *boloniensis* de Loriol [1].

Basal bed. Ammonites: *Pachysphinctes major* Spath [2]; *Pachysphinctes* sp. indet. [2]; *Aspidoceras* sp. indet. [3]; *Simaspidoceras irregulare* (Dacqué) [1]. **Bivalves:** *Palaeonucula* sp. [6], *Indogrammatodon egertonianus* (Stoliczka) [1], *Neocrassina spitiensis* (Stoliczka [sensu Holdhaus]) [3].

Lower marls:

2 m below top. Ammonites: *Aspidoceras longispinum* (J. de C. Sowerby) [1]; *Laevaptychus* [4].

Row of large doggers 8.5–9 m above base. Ammonites: *Taramelliceras (T.) pseudoflexuosum* (Favre) [3], *Taramelliceras* sp. indet. [2], *Lamellaptychus* [14], *Orthaspidoceras avellanum* (Zittel) [16], *Laevaptychus* [37], *Lithacoceras (Subplanites) mombassanum* (Dacqué) [26]. **Brachiopod:** *Acanthothiris* sp. nov. [1]. **Bivalves:** *Palaeonucula* sp. [ca.70], *Indogrammatodon* sp. [ca.70], ?*Grammatodon* sp. [ca.30], ?*Parainoceramus* sp. [1], *Nannogyra fourtaui* (Stefanini) [1], *'Lucina'* sp. [1], *Neocrassina* aff. *spitiensis* (Stoliczka [sensu Holdhaus]) [35], ?*Trautscholdia* sp. [1], ?*Freiastarte* sp. [4]. **Gastropods:** *Pleurotomaria* sp. [2], *Proconulus arabiensis* (Newton) [22], *'Margarites'* sp. [ca.50], *Pietteia* sp. [14].

Naifa Formation, Billum Member:

Basal 5m. Ammonites: *Epimayaites* sp. indet. [2], *Paryphoceras grayi* (Spath) [1], *Larcheria gredingensis* (Wegele) [1], *Orthosphinctes polygyratus* (Reinecke) [20].

Jebel Billum, eastern end, bank and cliff on north side of road (N14°17'51" E48°29'14")

Qishn Formation:

***Orbitolina* Limestone. Echinoids:** *Allomma* sp. nov. [1], *Heteraster* aff. *oblongus* (Brogniart) [1], *Leptosalenia* sp. [1], *Tetragramma ?variolare* (Brogniart) [1].

Upper part, below *Orbitolina* Limestone. Bivalves: *Lithophaga* sp. [?], *Neithea ?atava* Roemer [3], *'Exogyra'* cf. *tuberculifera* Koch & Dunker [1], ?*Amphidonte* sp. [?]. **Gastropods:** *Pseudonerinea* sp. [1]. ?*Harpagodes* sp. [7].

Middle part. Bivalves: *Cucullaea* sp. [1], *Neithea atava* Roemer [6], *'Exogyra'* cf. *tuberculifera* Koch & Dunker [12], ?*Amphidonte latissima* (Lamarck) [10], ?*Amphidonte* sp. [1], *Linotrigonia* or *Pterotrigonia* sp. [3], *Pholadomya valangiensis* Pictet & Campiche [13]. **Gastropods:** *Harpagodes* sp. [19].

Limestones 3.5 m thick at base of formation. Ammonite: *Crioceratites (C.)* cf. *villiersianum* (d'Orbigny) [1]. **Bivalves:** *Chondrodonta* ?sp. nov. [14]. **Gastropods:** *Harpagodes* sp. [8].

Hajar Formation, Mintaq Member:

Marls, 5.3 m below top. Ammonites: *Substeueroceras koeneni* (Steuer) [12], *Substeueroceras striatum* sp. nov. [1]

Massive limestone, 8.3 m below top. Ammonites: *Uhligites kraffti* (Uhlig) [2], *Virgatosphinctes* cf. *broilii* (Uhlig) [13], *Choicensisphinctes limitis* (Burckhardt) [9], *Substeueroceras koeneni* (Steuer) [2], *Substeueroceras striatum* sp. nov. [5]. *Blanfordiceras wallichi* (Gray) [1]. **Bivalves:** ?*Heterodiceras* sp. [2], *Arctostrea hastellata* (Schlotheim) [1].

Hajar Formation, Arus Member:

Marls, 26.5 m above base. Ammonites: *Uhligites* sp. indet. [1], *Aspidoceras* sp. indet. [3], *Laevaptychus* [16], *Spiticeras* sp. indet. [1], *Virgatosphinctes* cf. *broilii* (Uhlig) [22], *Choicensisphinctes limitis* (Burckhardt) [8], *Berriasella (B.) oppeli* (Kilian) [18], *Berriasella* sp. indet. [22], *Substeueroceras koeneni* (Steuer) [8]. *Malbosiceras* cf. *aizyensis* Mazenot [8]. **Bivalves:** *Palaeonucula* sp. [2], *Neocrassina* cf. *duboisiana* (d'Orbigny) [1], *Neocrassina spitiensis* (Stoliczka [sensu Holdhaus]) [52].

Basal coral bed; massive colony of fasciculate corals or stromatoporoid *Shuqraia*. Corals [22]. **Bivalves:** *'Gryphaea' balli* (Stefanini) [1], *Arctostrea hastellata* (Schlotheim) [1],

?*Neocrassina* sp. [1]. **Gastropods:** ?*Discotectus* sp. [1], '*Turbo*' sp. [1], ?'*Neritopsis*' sp. [1].

Naifa Formation, Billum Member:

Central part. Bivalves: *Falcimytilus jurensis* (Roemer) [1], *Actinostreon solitaria kindopeensis* (Cox) [6].

Jebel Billum, long eastern Jurassic cliff, Perisphinctid Cliff (N14°18'19" E48°28'35")

Naifa Formation, Billum Member:

Limestone pavement, 7 m above base. Ammonites: *Paryphoceras grayi* (Spath) (photo only) [1], *Larcheria gredingensis* (Wegele) [4, including 1 as photo only], *Orthosphinctes polygyratus* (Reinecke) [19, including 9 as photos only], *Idoceras ahwarense* sp. nov. (loose, ?fallen from higher in Billum Member) [1], *Euaspidoceras* sp. indet. (photo only) [1].

***Microthyridina* Beds, 4 m and 9 m above base. Brachiopods:** *Kallirhynchia* sp. [3], *Somalirhynchia* cf. *arabica* Cooper [4], *Microthyridina farquharsoni* Muir-Wood [50]. **Echinoid:** *Pseudocidaris* aff. *thurmanni* (Agassiz) [1]. **Crinoid:** ?*Millericrinus* sp. [1]. **Bivalves:** *Falcimytilus jurensis* (Roemer) [?], *Indogrammatodon egertonianus* (Stoliczka) [3], *Camptonectes* sp. [2], ?*Limaria* sp. [1], ?*Deltoideum delta* (Smith) [?], *Nannogyra fourtaui* (Stefanini) [7], *Actinostreon solitaria kindopeensis* (Cox) [1], *Trigonia* sp. [3], *Colpomya* sp. [8].

Jebel Billum, east end, 1 km south-west of Perisphinctid Cliff (N14°18'06" E48°28'22")

Shuqra Formation:

Middle Shuqra:

Lower part. Bivalves: '*Brachidontes*' *somalicus* Cox [2], *Pholadomya ?ovalis* (J. Sowerby) [1]. **Gastropod:** *Ampullospira* sp. [1].

Loose. Brachiopods: *Somalirhynchia arabica* Cooper [19], *S. subcircularis* Cooper [8].

Loose, mixed Lower/Middle Shuqra. Brachiopods: *Conarosia* sp. [4], *Daghanirhynchia sulcata* Cooper [15], *Daghanirhynchia* sp. [58], *Bihenithyris bihenensis* Muir-Wood [23], *B. mediocostata* Cooper [4], *Dorsoplicathyris* sp. [13], ?'*Stiphrothyris*' sp. [14]. **Echinoid:** *Acrosalenia (Recrosalenia) somaliensis* Currie [1]. **Bivalves:** *Grammatodon* sp. [1], '*Brachidontes*' *somalicus* Cox [9], *Modiolus* cf. *bipartitus* J. Sowerby [1], *Eligmus* sp. [1], *Spondylopecten* cf. *subpunctatus* (Münster) [1], *Eopecten* cf. *aubreyi* (Douvillé) [1], *Plagiostoma ?harronis* Dacqué [1], ?'*Gryphaea*' *balli* (Stefanini) [1], *Actinostreon solitaria* (J. Sowerby) [1], ?*Neocrassina* sp. [1], *Procyprina hunti* (Cox) [2], ?*Eocallista krenkeli* Cox [1], *Ceratomyopsis somaliensis* (Weir) [16], ?*Tellurimya* ?sp. nov. [1], *Pholadomya ?ovalis* (J. Sowerby) [1], *Bucardiomya somaliensis* (Cox) [3], *Bucardiomya aubreyi* (Douvillé) [4], *Ceratomya* cf. *pittieri* (de Loriol) [2], *C.* cf. *wimmisensis* (Gilliéron) [1]. **Gastropods:** *Ampullospira* sp. [1], *Nerinella* sp. [4].

Lower Shuqra:

Near base. Gastropods: *Nerinella* sp. [7].

Loose. Brachiopods: *Conarosia rotundata* Cooper [4], *Daghanirhynchia sulcata* Cooper [18], *Bihenithyris* cf. *bihenensis* Muir-Wood [12], ?'*Stiphrothyris*' sp. [2]. **Echinoid:** *Bothriopygus somaliensis* (Currie) [1]. **Stromatoporoid:** *Shuqraia* sp. [5]. **Corals** [4]. **Bivalves:** *Plagiostoma ?harronis* Dacqué [1], *Actinostreon solitaria* (J. Sowerby) [2], '*Lucina*' sp. [5], ?*Mactromya* sp. [1], ?*Tendagurium* sp. [5], *Bucardiomya* cf. *lyrata* (J. Sowerby) [2], *Homomya* cf. *gibbosa* (J. Sowerby) [3], *Ceratomya* cf. *pittieri* (de Loriol) [1], ?*Colpomya* sp. [1]. **Gastropods:** *Ampullospira* sp. [3], ?*Nerinella* sp. [4].

Central Jebel Billum (south of main Jurassic cliff) (N14°19'00" E48°26'48")

Madbi Formation:

104.5 m above base (7.3 m below top). Bivalves: *Indogrammatodon egertonianus* (Stoliczka) [4], *Modiolus* cf. *bipartitus* J. Sowerby [2], *Nannogyra fourtaui* (Stefanini) [4], *Trigonia* sp. [1].

87 m above base. Brachiopods: *Somalirhynchia africana* Weir [6], *Somalithyris bihendulensis* Muir-Wood [4], *Somalithyris* cf. *somaliensis* Weir [2]. **Bivalves:** *Indogrammatodon egertonianus* (Stoliczka) sp. [3], *Nannogyra fourtaui* (Stefanini) [20], ?*Actinostreon* sp. [1], *Trigonia* sp. [1].

65.3–67.4 m above base. Brachiopods: *Microthyridina farquharsoni* Muir-Wood [14]. **Bivalves:** *Camptonectes* sp., ?*Trigonia* sp., ?*Neocrassina* sp. [1].

Upper Storm Bed, 46–48 m above base. Brachiopods: *Somalirhynchia arabica* Cooper [7], *Bihenithyris* sp. [6], *Microthyridina farquharsoni* Muir-Wood [22]. **Bivalves:** *Indogrammatodon egertonianus* (Stoliczka) [5], *Modiolus* cf. *bipartitus* J. Sowerby [2], '*Posidonia*' *somaliensis* Cox [few], *Eopecten* sp., ?*Plagiostoma* sp. [few], *Deltoideum delta* (Smith) [18], *Nannogyra fourtaui* (Stefanini) [40], *Actinostreon* aff. *solitaria* (J. Sowerby) [3].

32–42 m above base. Brachiopods: *Somalirhynchia africana* var. *smelliei* Weir [8], *S.* cf. *arabica* Cooper [6], *Somalirhynchia* sp. [1], *Avonothyris* sp. [12], *Bihenithyris* sp. [11], *Cerethyris* sp., [fragments, few], *Mycerosia ?amygdaliformis* Cooper [3], *Ptyctothyris daghanensis* Muir-Wood [1]. **Bivalves:** '*Posidonia*' *somaliensis* Cox [1], *Deltoideum delta* (Smith) [1], *Trigonia* sp. [1], *Colpomya* sp. [1].

Lower Storm Bed, at base of formation. Ammonite: *Laevaptychus* [1]. **Brachiopods:** *Somalirhynchia africana* var. *smelliei* Weir [4], *S.* cf. *africana* Weir [20], *S.* cf. *arabica* Cooper [38], *Somalirhynchia* sp. (large, coarsely costate) [2], *Bihenithyris weiri* Muir-Wood [2], *Cererithyris* cf. *wyvillei* (Weir) [4], *Ptyctothyris daghaniensis* Muir-Wood [8], ?*Rugetela* sp. [2 fragments]. **Bivalves:** *Palaeonucula* sp. [2], *Indogrammatodon egertonianus* (Stoliczka) [26], '*Posidonia*' *somaliensis* Cox [31], *Camptonectes* sp. [2], *Nannogyra fourtaui* (Stefanini) [72], *Actinostreon* aff. *solitaria* (J. Sowerby) [2], *Trigonia* sp. [1], *Neocrassina* aff. *unilateralis* (J. de C. Sowerby) [4]. **Gastropods:** *Proconulus arabiensis* (Newton) [17].

Shuqra Formation: Upper Shuqra:

1 m below top. Bivalves: ?*Procyprina* sp. [20].

7–10 m below top. Brachiopods: *Somalirhynchia* fragments [15]. **Echinoids:** *Acrosalenia (Recrosalenia) somaliensis* Currie [3], ?*Plegiocidaris* sp. [1]. **Crinoids:** ?*Angulocrinus* sp. [2], ?*Millericrinus* sp. [2]. **Bivalves:** *Nannogyra fourtaui* (Stefanini) [10], *Actinostreon solitaria* (J. Sowerby) [3].

17 m below top, rubbly marls and nodular limestones. Ammonite: *Erymnoceras (Pacherymnoceras) jarryi* (Douvillé) [1].

Brachiopods: *Somalirhynchia africana* Weir [13], Terebratulidae indet. [2]. **Bivalves:** *'Brachidontes' somalicus* Cox [5], *Modiolus* cf. *bipartitus* J. Sowerby [2], *Eligmus humei* (Stefanini) [8], *Entolium* sp. [1], *Eopecten* cf. *aubreyi* (Douvillé) [1], *Plagiostoma ?harronis* Dacqué [4], *'Gryphaea' balli* sp. [1], *Nannogyra fourtaui* (Stefanini) [1], *Mactromya* sp. [2], *Tendagurium* cf. *propebanneiana* (Dietrich) [2], *Procyprina hunti* (Cox) [4], *Ceratomyopsis somaliensis* (Weir) [3], *Bucardiomya somaliensis* (Cox) [1], *Ceratomya* cf. *pittieri* (de Loriol) [2]. **Gastropods:** *Rhabdoconcha* sp. [1], *Ampullospira* sp. [2], *'Bulla'* sp. [1].

21–23 m below top (0–2 m above Nautiloid Bed), *Eligmus aualites* horizon. Brachiopods: *Somaliryhnchia* cf. *arabica* Cooper [16], *Bihenithyris* sp. [5]. **Echinoid:** *Acrosalenia (Recrosalenia) somaliensis* Currie [4]. **Crinoid:** *?Angulocrinus* sp. [1]. **Bivalves:** *?Palaeonucula* sp. [1], *'Brachidontes' somalicus* Cox [3], *Eligmus aualites* (Stefanini) [50+], *Eligmus* sp. [2], *?'Gryphaea' balli* (Stefanini) [8], *Nannogyra fourtaui* (Stefanini) [5], *Actinostreon solitaria* (J. Sowerby) [11], *Arctostrea eruca* (Lamarck) [1], *Mactromya* sp. [2], *Procyprina hunti* (Cox) [4], *?Eocallista krenkeli* Cox [5], *Ceratomyopsis somaliensis* (Weir) [5], *Tellurimya* ?sp. nov. [1], *Ceratomya* cf. *pittieri* (de Loriol) [1]. **Gastropods:** *?Pietteia* sp. [1].

23 m below top, limestone, 0.5 m thick, the Nautiloid Bed. Nautiloids: *Paracenoceras meridionale* Tintant [5], *P. calloviense* (Oppel) [1].

23–26 m below top (incl. Nautiloid Bed). Brachiopods: *Conarosia* sp. [15], *Somalirhynchia arabica* Cooper [9], *Bihenithyris barringtoni* Muir-Wood [1], *B. weiri* Muir-Wood [4]. **Bivalves:** *Parallelodon* sp. [1], *'Brachidontes' somalicus* Cox [27], *Modiolus* cf. *bipartitus* J. Sowerby [1], *Eligmus aualites* (Stefanini) [4], *E. humei* (Stefanini) [2], *Plagiostoma ?harronis* Dacqué [1], *Plagiostoma* sp. [1], *'Gryphaea' balli* (Stefanini) [6], *Nannogyra fourtaui* (Stefanini) [4], *Actinostreon solitaria* (J. Sowerby) [6], *Myoconcha* sp. [1], *Tendagurium* cf. *propebanneiana* (Dietrich) [3], *Procyprina hunti* (Cox) [15], *?Eocallista krenkeli* Cox [2], *Ceratomyopsis arabica* (Cox) [6], *Bucardiomya somaliensis* (Cox) [2], *Ceratomya* cf. *pittieri* (de Loriol) [2], *Ceratomya* cf. *wimmisensis* (Gilliéron) [1]. **Gastropods:** *Rhabdoconcha* sp. [3], *Ampullospira* sp. [2].

27–30 m below top. Brachiopods: *Somalirhynchia* cf. *africana* Weir [12], *Somalirhynchia* sp. [4], *Arabicella arabis* Cooper [1], *A. ovalis* Cooper [5], *Arapsopleurum* cf. *arabicum* Cooper [2], *A. rotundum* Cooper [8], *Arapsothyris angusta* Cooper [1], *?'Stiphrothyris'* sp. [1]. **Bivalves:** *Parallelodon* sp. [2], *'Brachidontes' somalicus* Cox [10], *?Modiolus* cf. *bipartitus* (J. Sowerby) [1], *Stegoconcha* sp. [few], *Trichites* sp. [few], *?Pteroperna* sp. [1], *Eligmus aualites* (Stefanini) [2], *E. humei* (Stefanini) [2], *Spondylopecten* cf. *subpunctatus* (Münster) [2], *Eopecten* cf. *aubreyi* (Douvillé) [1], *Plagiostoma* sp., *'Gryphaea' balli* (Stefanini) [1], *Nannogyra fourtaui* (Stefanini) [1], *?Actinostreon* sp. [1], *Trigonia* sp. [1], *Procyprina hunti* (Cox) [4], *Ceratomyopsis somaliensis* (Weir) [5], *Bucardiomya somaliensis* (Cox) [4], *B. aubreyi* (Douvillé) [1], *Ceratomya* cf. *wimmisensis* (de Loriol) [3]. **Gastropods:** *Ampullospira* sp. [4], *?Nerinella* sp. [3].

38.5–45.5 m below top. Brachiopods: *Conarosia* sp. [33], *Daghanirhynchia* sp. [4], *Somalirhynchia africana* Weir [12], *S. arabica* Cooper [4], *S. somalica* (Dacqué) [2], *Somalirhynchia* sp. nov. [31], *Bihenithyris barringtoni* Muir-Wood [12], *B. weiri* Muir-Wood [3], *Cererithyris* cf. *wyvillei* (Weir) [40], *Ptyctothyris daghaniensis* Muir-Wood [3], *'Terebratula' aulites* Stefanini [1]. **Echinoids:** *Acrosalenia (Recrosalenia) somaliensis* Currie [5]. **Bivalves:** *Parallelodon* sp. [2], *'Brachidontes' somalicus* Cox [4], *Modiolus* cf. *bipartitus* (J. Sowerby) [8], *Eligmus humei* (Stefanini) [3], *E.* cf. *weiri* Cox [2], *Spondylopecten* cf. *subpunctatus* (Münster) [2], *'Gryphaea' balli* (Stefanini) [3], *?Nannogyra fourtaui* (Stefanini), *Actinostreon solitaria* (J. Sowerby) [4], *Trigonia* sp. [1], *Myoconcha* sp. [1], *Tendagurium* cf. *propebanneiana* (Dietrich) [1], *Procyprina hunti* (Cox) [17], *?Eocallista krenkeli* Cox [2], *Ceratomyopsis somaliensis* (Weir) [5], *Bucardiomya aubreyi* (Douvillé) [1], *B. somaliensis* (Cox) [4], *Ceratomya* cf. *wimmisensis* (de Loriol) [1]. **Gastropods:** *Rhabdoconcha* sp. [1], *Ampullospira* sp. [8].

Loose, lower part. Bivalves: *Eligmus humei* (Stefanini) [3], *E. aualites* Stefanini [1], *Ceratomya* sp. [2], *Pholadomya aubreyi* (Douvillé). **Gastropods:** *'Natica'* sp. [1], *Rhabdoconcha* sp. [1].

Middle Shuqra:

Top 3 m. Brachiopods: *Somalirhynchia* cf. *arabica* Cooper [18], *S. somalica* (Dacqué) [1], *Bihenithryis* cf. *barringtoni* Muir-Wood [1], *Cererithyris* sp. [16], *Ornithella* sp. [1]. **Bivalves:** *Palaeonucula* sp. [1], *'Brachidontes' somalicus* Cox [6], *Modiolus* cf. *imbricatus* J. Sowerby [5], *Eligmus* sp. [6], *Spondylopecten* cf. *subpunctatus* (Münster) [5], *Eopecten* cf. *aubreyi* (Douvillé) [1], *Plagiostoma* sp. [1], *Actinostreon solitaria* (J. Sowerby) [6], *Trigonia* sp. [2], *'Lucina'* sp. [1], *?Tendagurium* sp. [1], *Procyprina hunti* (Cox) [2], *Pseudotrapezium* sp. of Cox [1], *Ceratomyopsis somaliensis* (Weir) [12], *Tellurimya* ?sp. nov. [1], *Bucardiomya somaliensis* (Cox) [3], *Bucardiomya aubreyi* (Douvillé) [4], *Ceratomya* cf. *wimmisensis* (de Loriol) [4], *?Plectomya* sp. [5]. **Gastropods:** *Discohelix* sp. [1], *Ampullospira* sp. [9], *?Nerinella* sp. [many], *Cylindrobullina* sp. [1].

Lower part. Bivalves: *Pseudotrapezium* sp. of Cox [1], *?Eocallista krenkeli* Cox [1]. **Gastropod**: *?Nerinella* sp. [1].

A slumped section of the Upper Shuqra was also examined 1 km to the east, below the main cliff:

Above *Eligmus aualites* horizon. Brachiopods: *Somalirhynchia* cf. *arabica* Cooper [108], *Apatecosia* sp. [7], *Arabicella* sp. [ca.20], *?Arapsopleurum* sp. [ca.15], *Bihenithyris* cf. *quadrilobata* Cooper [5], *B. weiri* Muir-Wood [2], *Cererithyris* sp. [ca.20], *Somalithyris macfadyeni* Muir-Wood [3]. **Bivalves:** *'Brachidontes' somalicus* Cox [7], *Lithophaga* sp., *Modiolus* cf. *bipartitus* J. Sowerby [3], *Eligmus humei* (Stefanini) [29], *E. aualites* (Stefanini) [3], *Spondylopecten* cf. *subpunctatus* (Münster) [1], *Eopecten* cf. *aubreyi* (Douvillé) [1], *Plagiostoma* sp. [1], *'Gryphaea' balli* (Stefanini) [14], *Deltoideum delta* (Smith) [1], *Nannogyra fourtaui* (Stefanini) [6], *Actinostreon solitaria* (J. Sowerby) [36], *Myoconcha* sp. [1], *Tendagurium* cf. *propebanneiana* (Dietrich) [1], *Procyprina hunti* (Cox) [7], *Pseudotrapezium* sp. of Cox [1], *Ceratomyopsis somaliensis* (Weir) [5], *Bucardiomya somaliensis* (Cox) [5], *Ceratomya* cf. *wimmisensis* (Gilliéron) [3], *?Pleuromya* sp. [1]. **Gastropods:** *Ampullospira* sp. [9], *?Bourguetia* sp. [1].

***Eligmus aualites* horizon. Brachiopods:** *Conarosia* sp. [10], *Somaliryhnchia* cf. *arabica* Cooper [68], *Cererithyris* sp. [25], *?Dissoria obscura* Cooper [3], *Somalithyris macfadyeni* Muir-Wood [30]. **Bivalves:** *Palaeonucula* sp. [1], *'Brachidontes' somalicus* Cox [8], *Modiolus* cf. *bipartitus* J. Sowerby [1], *Eligmus aualites* (Stefanini) [30+], *E. humei* (Stefanini) [1], *Limaria* sp. [2], *'Gryphaea' balli* (Stefanini) [3], *Nannogyra fourtaui* (Stefanini) [7], *Actinostreon solitaria* (J. Sowerby) [10], *?Sphaera* sp. [1], *Procyprina hunti* (Cox) [7], *?Eocallista krenkeli* Cox [6], *Tellurimya* ?sp. nov. [1], *Bucardiomya somaliensis* (Cox) [1]. **Gastropods:** *Ampullospira* sp. [6].

Jebel Billum, western entrance road cutting (N14°18'48" E48°25'53")

Naifa Formation, Billum Member:

Argillaceous limestone, ca. 20 m above base. Ammonites: *Glochiceras (G.) subclausum* (Oppel) [5]; *Orthosphinctes polygyratus* (Reinecke) [1]. **Bivalves:** *Indogrammatodon egertonianus* (Stoliczka) [3], *Nannogyra fourtaui* (Stefanini) [many].

Limestone, in basal 5m. Ammonite: *Paryphoceras grayi* (Spath) [1].

Wadi Arus, road gorge leading into southern end of Wadi

Hajar Formation, Mintaq Member:

Limestone, 16 m below Qishn Formation. Ammonite: *Aspidoceras* sp. indet. (photograph of 0.5 m diameter specimen).

Flaggy limestone, 31.5 m below Qishn Formation. Ammonites: *Substeueroceras striatus* sp. nov. [27]; *Protacanthodiscus*. sp. indet. [4].

Wadi Arus, cliffs on east and west sides

Hajar Formation, Arus Member:

Microbialite boulders in basal 7m. Ammonites: *Pseudoclambites araense* sp. nov. [18], *Baeticoceras morrisi* sp. nov. [2], *Virgatosimoceras broilii* (Schneid) [1], *Aulacosphinctes spitiensis* (Uhlig) [1], *Aulacosphinctes natricoides* (Uhlig) [2], *Micracanthoceras fraudator* (Zittel) [1], *Himalayites* sp. indet. [1], *Spiticeras gregoryi* (Spath) [1], *Virgatosphinctes* cf. *broilii* (Uhlig) [1], *Berriasella (B.)* cf. *oxycostata* Mazenot [7], *Riasanites rjasanensis* (Lahusen) [2], *Blanfordiceras wallichi* (Gray) [1]. **Echinoid:** *Collyrites* cf. *loryi* (Gras) [1].

Wadi Arus, cliff on east side (N14°20'17" E48°23'34")

Naifa Formation, Kilya Member:

Astarte Bed, 0.3 m below top. Bivalves: *Neocrassina spitiensis* (Stoliczka [sensu Holdhaus]) [40].

Breadloaf Concretions, in marls 15–20 m above lowest exposure. Ammonites: *Taramelliceras (T.) pseudoflexuosum* (Favre) [2], *Taramelliceras (T.)* cf. *insistens* Hölder [4], *Haploceras staszycii* (Zejszner) [8], *Glochiceras (Lingulaticeras) pseudocarachteis* (Favre) [4], *Torquatisphinctes naifaensis* sp. nov. [1], *Sutneria weidmanni* Zeiss [7], *Pachysphinctes bathyplocus* (Waagen) [5], *Pachysphinctes major* Spath [5], *Idoceras ahwarense* sp. nov. [1], *Idoceras* cf. *balderum* (Oppel) [1], *Nebrodites hospes* (Neumayr) [1], *Simaspidoceras argobbae* (Dacqué) [8], *Laevaptychus* [6], *Lithacoceras (Subplanites) mombassanum* (Dacqué) [2], *Lithacoceras* sp. indet. [1]. **Bivalves:** *Parainoceramus* sp. [2], *Aulacomyella farquharsoni* Cox [15], *'Posidonia' somaliensis* Cox [many], *Liostrea* cf. *boloniensis* de Loriol [1].

Wadi Arus, cliff on west side (N14°20'29" E48°23'30")

Naifa Formation, Billum Member:

Top bed of limestone forming pavement at base of cliff. Ammonites: *Streblites plicodiscus* (Waagen) [4 photographs]; indet. perisphinctids (*?Torquatisphinctes*) [6 photographs]. **Bivalves:** *Parainoceramus* sp. [few].

Mintaq Salt Dome; southwestern exposure leading up to contact with Qishn Formation (N14°33'09" E48°02'35")

Qishn Formation:

73 m above base, *Orbitolina* Limestone. Echinoid: *Leptosalenia somaliensis* Hawkins [2]. **Bivalves:** *Amphidonte* sp. [2], *Pholadomya valangiensis* Pictet & Campiche [1]. **Gastropod:** *?Pseudomelania* sp. [1].

38–46 m above base, Lower Oyster Beds. Bivalves: *Lithophaga* sp., *'Exogyra'* cf. *tuberculifera* Koch & Dunker [many], *Trigonia* sp. [1], *Syriotrigonia picteti* (Coquand) [1], *Opis* sp. [1], *?Tendagurium* sp. [1]. **Gastropods:** *?Nerinella* sp. [6], *Procerithium* sp. [1].

Hajar Formation, Mintaq Member (metres above base in brackets are above the contact with the Sabatayn Formation):

Bed 149 (8.5 m limestones and marls; 150.0 m above base), 0.75 m above base. Ammonites: *?Protacanthodiscus* or *Neocosmoceras* spp. indet. [1]; *?Neocomites* sp. indet. [1].

Bed 96 (0.3 m limestone; 113.35 m above base). Ammonites: *Dalmasiceras* sp. indet. [2].

Bed 77 (0.2 m limestone with haemetite; 103.85 m above base). Ammonites: *Spiticeras (S.) pricei* sp. nov. [1].

Bed 75 (0.3 m brown limestone; 103.45 m above base). Ammonites: *Spiticeras (S.) pricei* sp. nov. [4]; *Berriasella* sp. indet. [1].

Bed 69 (0.2 m brown limestone; 101.55 m above base). Ammonites: *Haploceras umbilicatum* sp. nov. [1], *Spiticeras (S.) pricei* sp. nov. [6], *Spiticeras subspitiense* (Uhlig) [1], indet. berriasellid [1].

Bed 64 (0.5 m brown, fine-grained limestone nodules; 99.55 m above base). Ammonite: *Argentiniceras mintaqi* sp. nov. [1].

Bed 60 (0.35 m fine-grained brown limestone with abundant haemetite nodules; 98.0 m above base). Ammonites: *Aspidoceras* cf. *taverai* Checa [2], *Spiticeras (S.) pricei* sp. nov. [41], *Spiticeras* sp. indet. [1], *Berriasella (Elenaella) sevenieri* (Le Hégarat) [1], *Berriasella (Picteticeras) chomeracensis* (Toucas) [1], *Berriasella* spp. indet. [6], *Substeueroceras koeneni* (Steuer) [1], *Argentiniceras mintaqi* sp. nov. [1].

Bed 57 (0.3 m limestone; 97.2 m above base). Ammonites: *Haploceras umbilicatum* sp. nov. [2], *Aspidoceras* cf. *taverai* Checa [1], *Argentiniceras mintaqi* sp. nov. [2], *Argentiniceras mutatum* (Steuer) [1], *Spiticeras* sp. indet. [1]. **Echinoid:** *Collyrites* cf. *loryi* (Gras) [2].

Bed 36 (0.2 m brown limestone; 90.4 m above base). Ammonites: *Aspidoceras rogoznicense* (Zejszner) with *Laevaptychus* attached [2], *Spiticeras (S.) pricei* sp. nov. [4], *Spiticeras (S.)* sp. (thick, quadrate whorls) [1], *Spiticeras (S.)* sp. (compressed whorls, involute) [1], *Spiticeras (Negreliceras) obliquenodosum* (Retowski) [1], *Berriasella (Elenaella) sevenieri* (Le Hégarat) [1], *Malbosiceras* sp. indet. [1], Berriasellid s.l., microconch or deformed [1], *Argentiniceras mintaqi* sp. nov. [1], *Neocosmoceras* sp. indet. [1]

Bed 34 (0.3 m grey-brown limestone; 90.0 m above base). Ammonites: *Spiticeras (S.) subspitiense* (Uhlig) [1]; *Spiticeras (S.) pricei* sp. nov. [1].

Bed 31 (1.2 m brown, marly, rubbly limestone; 87.9 m above base): *Spiticeras (S.) spitiense* (Blanford) [1], *Spiticeras (S.) indicum* (Uhlig) [2], *Spiticeras (Negreliceras) paranegreli* Djanélidzé [1], Indet ?Spiticeratinid [1].

Bed 30 (0.3 m grey-brown, marly, nodular limestone; 87.6 m above base). Ammonites: *Aspidoceras* cf. *taverai* Checa [1]; *Laevaptychus* [6]; *Spiticeras pricei* sp. nov. [2]; *Spiticeras (Negreliceras)* cf. *obliquenodosum* (Retowski) [1]; indet. berriasellid [1].

Bed 29 (0.8 m brown, marly limestone; 86.8 m above base). Ammonites: *Spiticeras pricei* sp. nov. [1], *Spiticeras (Negreliceras) obliquenodosum* (Retowski) [1], *Laevaptychus* [5], *Berriasella (Picteticeras) chomeracensis* (Toucas) [1], *Berriasella* spp. indet. [1].

Bed 27 (1.3 m Grey-brown, fine-grained limestone; 85.1 m above base). Ammonites: *Spiticeras (S.) pricei* sp. nov. [3].

Bed 21 (0.4 m grey-brown, fine-grained limestone; 81.0 m above base). Ammonites: indet. ?berriasellids [3].

Bed 13 (0.3 m thinly laminated limestone; 60.7 m above base). Ammonites: indet. ?berriasellid [1].

Bed 3 (3.8 m grey, fine-grained, thin-bedded limestones, with marly partings; 27.5 m above base), 1 m above base. Ammonite: ?*Dalmasiceras* sp. indet. [1].

Bed 1 (25 m buff-grey, fine-grained limestones in beds 0.2–0.7 m thick), 0.4 m below top. Ammonite: *Substeueroceras striatum* sp. nov. [1].

Jebel Madbi (N14°21'20" E48°01')

Hajar Formation, Mintaq Member:

In upper part of member, on summit of Jebel Madbi. Ammonite: *Tirvonella occitanica* (Pictet) [2].

NOTE ADDED IN PROOF

After this paper had gone to print, a paper was published by Beydoun (1997, Introduction to the revised Mesozoic stratigraphy and nomenclature for Yemen, *Marine and Petroleum Geology*, **14** (6): 617–629) which made many revisions to the lithostratigraphical nomenclature of the Jurassic of Yemen. These are to be formalized in a new edition of the Yemen volume of the *Lexique Stratigraphique International (Paris)*, scheduled for publication in 1997, but which we have not seen.

The most far-reaching change is to the Upper Oxfordian to lowest Tithonian Naifa Formation, whose type locality is at Naifa Cliff, Ma'abir. Beydoun proposed to alter the type locality to the Mintaq Salt Dome, 65km to the north-west, where the rocks are Upper Tithonian and Berriasian in age. This is to be done because of past mis-correlation and misinterpretation of the age. However, such wholesale alteration of the type section of a formation is not permitted under Article 22 (c) of the North American Stratigraphic Code (NASC) which maintains:

'**Type section never changed**. – The definition and name of a stratigraphic unit are established at a type section (or locality) that, once specified, must not be changed' (NASC, 1983, *Bulletin American Association Petroleum Geologists*, **67:** 856).

We fully support the NASC's aim of achieving reasonable stability in lithostratigraphical nomenclature. In advancing such stability for the Jurassic rocks of Wadi Hajar and Yemen, we would make the following points:

1. An important purpose of lithostratigraphical nomenclature at Formation level is to name rocks units that are lithologically distinct, and are easily separable on the ground as mappable units. In Wadi Hajar the formations we use have widely different lithologies, and are based on those originally proposed by Beydoun (1964). Thus the Kohlan, Shuqra, Madbi, Naifa and Hajar Formations consist of markedly different arenaceous, calcareous, argillaceous, calcareous and calcareous rocks respectively, the latter two being separated by an unconformity and by detailed lithological differences. Such clear division of the Jurassic is abandoned by Beydoun's new proposals.
2. The Madbi Formation is argillaceous at its type locality on Jebel Madbi, and the term was used for the same rock division in Wadi Hajar by Beydoun (1964). Its extension upwards to include the heavily calcareous 'Madbi Porcellanites' (= our Billum Member; = Ma'abir Member newly proposed by Beydoun), then a calcareous 'Upper Madbi Shales' (= our Kilya Member) places widely differing lithologies in the Madbi Formation. The overlying Billum Member makes such a marked contrast to the argillaceous Madbi Formation that it needs a different formation name, for which Naifa Formation is available, as originally defined with its type locality at Naifa Cliff, near Ma'abir. Billum Member (or Ma'abir Member if this is held to have priority) is the name for the heavily calcified lower half, and Kilya Member for the calcareous upper half. A 'Madbi Formation' for all the rocks from the bottom of the Madbi to the top of the Naifa Formation as used by us, embraces too many markedly different lithologies, over too large an age range from the bottom of the Oxfordian to the bottom zone of the Tithonian.
3. Beydoun (1964) was already in possession of ammonite evidence that the date of the Naifa Formation at its type locality was Upper Oxfordian/Lower Kimmeridgian, and collections of ammonites giving good dating evidence can be obtained in abundance in Wadi Hajar, as the present paper shows. Miscorrelation from Naifa Cliff to Wadi Arus then Mintaq (where microfossil evidence showed that the date of the wrongly identified 'Naifa' Formation was Upper Tithonian/Berriasian) cannot be used as a reason for the illegal alteration of the type locality of the Naifa Formation.
4. Nor is the subsequent misuse of the term 'Naifa Formation' (many in unpublished company reports) sufficient reason to alter its type locality and age to the Mintaq Salt Dome and Upper Tithonian to Berriasian. The rocks at Mintaq are similar in lithology to those of the Naifa Formation at Naifa Cliff, but they are wholly different in age and are separated from the latter by an unconformity and intermediate beds (our Arus Member) that are lithologically different. Our new division, the Mintaq Member, Hajar Formation, is available for the Mintaq rocks.
5. For reasons of priority, clear lithological differentiation and inviolability of the type section, Beydoun's original nomenclature and usage, as interpreted and refined with age dating in our paper, should be retained in preference to the extension of the Madbi Formation upwards to include rocks of entirely different lithology, and the alteration of the age and type locality of the Naifa Formation. The subsurface data now available from many parts of Yemen does not invalidate the lithostratigraphical nomenclature used for Wadi Hajar. If rocks of different lithology and/or intermediate age are present in the subsurface, they can be given new formation names applicable to the local conditions. It seems, however, that age dating for the subsurface rocks may not be known in sufficient detail to make good comparisons with the rocks in Wadi Hajar.